THE

STUDENT'S ELEMENTS OF GEOLOGY

By Sir CHARLES LYELL, Bart., F.R.S.

AUTHOR OF 'THE PRINCIPLES OF GEOLOGY' 'THE ANTIQUITY OF MAN' ETC.

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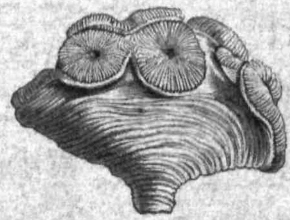

Thecosmilia annularis

FOURTH EDITION, REVISED

By P. MARTIN DUNCAN, F.R.S.

PROFESSOR OF GEOLOGY IN KING'S COLLEGE, LONDON; LECTURER ON GEOLOGY AT THE ROYAL INDIAN ENGINEERING COLLEGE, COOPER'S HILL; EXAMINER IN GEOLOGY IN THE UNIVERSITY OF LONDON; VICE-PRESIDENT LINNEAN SOCIETY; ETC.

WITH A TABLE OF BRITISH FOSSILS AND MORE THAN 600 ILLUSTRATIONS

LONDON
JOHN MURRAY, ALBEMARLE STREET
1885

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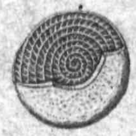
TERTIARY  or CAINOZOIC

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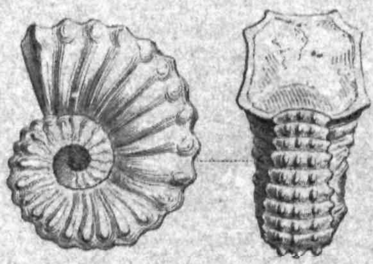
SECONDARY  or MESOZOIC

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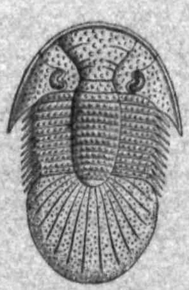
PRIMARY  or PALÆOZOIC

Bronteus flabellifer

AUTHOR'S PREFACE.

BETWEEN the years 1838 and 1865 I published six editions of the 'Elements of Geology,' beginning with a small duodecimo volume, which increased with each successive edition, as new facts accumulated, until in 1865 it had become a large and somewhat expensive work.

When a seventh edition was called for, I was strongly urged by my friends to attempt to bring the book back again to a size more approaching the original, so that it might be within the reach of the ordinary student. In order to do this I resolved, in the first place, to omit some theoretical discussions which belonged more properly to my 'Principles of Geology,' and further to confine myself to examples of British rocks, wherever this could be done; only seeking foreign illustrations when, as in the case of the Upper Miocene or Falunian Tertiaries, no good representatives were to be found in this country.

I therefore published in 1871 what was substantially a new work under the title of 'The Student's Elements of Geology,' and the success of the attempt has been proved by the steady demand which has exhausted an unusually large edition in less than three years.

The present work has been carefully revised and corrected, with the addition of such new matter as the plan of the volume permitted.

I have also added a new and very important table (see p. 577) illustrative of the successive appearance and development in time of the different forms of animal and vegetable life throughout the British fossiliferous rocks. This table has been compiled for me by Mr. ETHERIDGE, of the London School of Mines, from materials which he has been collecting for many years.

Among the numerous scientific friends who have rendered me valuable assistance in different parts of this new edition, I should wish especially to mention Mr. SEARLES WOOD, Mr. DAVID FORBES, Mr. JUDD, and the Rev. T. G. BONNEY, of St. John's, Cambridge.

CHARLES LYELL.

73 HARLEY STREET:
February 1874.

PREFACE

TO

THE FOURTH EDITION.

THIS book was written by the late SIR CHARLES LYELL in order to meet the requirements of those students who are entirely ignorant of the science of Geology.

The work contained those parts of Sir CHARLES LYELL'S celebrated book, 'The Elements of Geology,' which were the most indispensable to a beginner, and was published in 1871. It was subsequently revised by SIR CHARLES LYELL in 1874, and he availed himself of the assistance of Messrs. Etheridge, Searles Wood, David Forbes, Professor Judd, and the Rev. Professor Bonney.

A Third Edition was published in 1878, and it was the result of careful correction and revision on the part of Mr. Leonard Lyell, assisted by Professor Judd and Mr. Etheridge, sen.

The utility of the book has been proved by the necessity of producing these successive editions, and, when the work went out of print some years since, a very great want was felt by students and teachers.

The present revised edition contains the results of the more important geological investigations which have taken place since the appearance of the last edition, but the

original plan and character of the book are preserved. I have availed myself of the works of the distinguished geologists whose names have been mentioned above, and also of the writings of Professor A. Geikie, Director of the Geological Survey of the United Kingdom; of Professor Prestwich, of Oxford; and Professor T. McKenny Hughes, of Cambridge. It has been a most pleasing task to follow the thoughts and to continue in the method of the great man to whom the science of Geology is so greatly indebted, and I sincerely hope that these pages may be as useful as those of the original book.

P. MARTIN DUNCAN.

1884.

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STUDENT'S

ELEMENTS OF GEOLOGY.

Owing to a mishap of the Editor, it is necessary that he should ask the readers of this book to make the following corrections :—

On page 582 of the list of British fossils—

Place 'Class Rhizopoda' above the 'Order Foraminifera' and 'Class Spongida' below it.

Remove the long lines which indicate the range of 'Class Hydrozoa.'

Below 'Class Alcyonaria' place 'Fam. Pennatulidæ' with a line to correspond with the Eocene.

Below 'Fam. Helioporidæ' place 'Fam. Favositidæ and allied Tabulate forms.' Place lines to correspond in the L. & U. Silurian, the Devonian, and Carboniferous. Extend the lines of the Helioporidæ into the L. Silurian.

Lyell's Student's Elements

tinct substances, such as clay, chalk, sand, limestone, coal, slate, granite, and the like ; but previously to observation it is commonly imagined that all these have remained from the first in

the state in which we now see them—that they were created in their present form and in their present position. The geologist soon comes to a different conclusion, discovering proofs that the external parts of the earth were not all produced, in the beginning of things, in the state in which we now behold them, nor in an instant of time. On the contrary, he can show that they have acquired their actual configuration and condition gradually, under a great variety of circumstances, and at successive periods, during each of which distinct races of living beings have flourished on the land and in the waters, the remains of these creatures still lying buried in the crust of the earth.

By the 'earth's crust' is meant that small portion of the exterior of our planet which is accessible to human observation. It comprises not merely all the parts of the earth which are laid open in precipices, or in cliffs overhanging a river or the sea, or which the miner may reveal in artificial excavations; but the whole of that outer covering of the planet on which we are enabled to reason by observations made at or near the surface. These reasonings may extend to a depth of perhaps twenty miles, a very fractional part of the distance from the surface to the centre of the globe. The remark is just; but although the dimensions of such a crust are, in truth, insignificant when compared to the entire globe, yet they are vast, and of magnificent extent in relation to man and to the organic beings which people our globe. Referring to this standard of magnitude, the geologist may admire the ample limits of his domain, and admit, at the same time, that not only the exterior of the planet, but the entire earth, is but an atom in the midst of the countless worlds surveyed by the astronomer.

The materials of this crust are not thrown together confusedly; but distinct mineral masses, called rocks, are found to occupy definite spaces, and to exhibit a certain order of arrangement. The term *rock* is applied indifferently by geologists to all these substances, whether they be soft or stony, for clay and sand are included in the term, and some have even brought peat under this denomination. Our old writers endeavoured to avoid offering such violence to our language, by speaking of the component materials of the earth as consisting of rocks and *soils*. But there is often so insensible a passage from a soft and incoherent state to that of stone, that geologists of all countries have found it indispensable to have one technical term to include both, and in this sense we find *roche* applied in French, *rocca* in Italian, and *felsart* in German. The beginner, however, must constantly bear in mind that the term rock by no means in-

variably implies that a mineral mass is in an indurated or stony condition.

The most natural and convenient mode of classifying the various rocks which compose the earth's crust is to refer, to a certain extent, to their origin and relative age, but mainly to their physical structure and chemical composition. A useful classification which refers to the origin of the rocks, or to the different circumstances and causes by which they have been produced, separates the rocks, firstly, into those which are the products of aqueous or watery action; secondly, those which are aërial in their method of production and accumulation; and, thirdly, those which are volcanic, and the result of igneous action near the surface of the earth. A fourth group contains plutonic rocks, or deeply-seated masses which had an igneous origin; and a fifth group contains rocks which have undergone chemical and mechanical alterations, and are called metamorphic.

Aqueous rocks.—The aqueous rocks, sometimes called the sedimentary, or fossiliferous, cover a larger part of the earth's surface than any others, and they have been formed under water. Some consist of mechanical deposits (pebbles, sand, and mud), and others are of organic origin, especially the limestones. A few are of chemical origin like calc-sinter. These rocks are usually *stratified*, or divided into distinct layers, or strata. The term *stratum* means simply a bed, or anything spread out or *strewed* over a given surface; and we infer that these strata have been generally spread out by the action of water, from what we daily see taking place near the mouths of rivers, or on the land during temporary inundations. For, whenever a running stream charged with mud or sand has its velocity checked, as when it enters a lake or sea, or overflows a plain, the sediment, previously held in suspension by the motion of the water, sinks by its own gravity to the bottom. In this manner layers of mud and sand are thrown down one upon another.

If we drain a lake which has been fed by a small stream, we frequently find a series of deposits at the bottom, disposed with considerable regularity, one above the other; the uppermost, perhaps, may be a stratum of peat, next below is a more dense and solid variety of the same material; still lower a bed of shell-marl, alternating with peat or sand, and then other beds of marl, divided by layers of clay. Now, if a second pit be sunk through the same continuous lacustrine *formation* at some distance from the first, nearly the same set of beds is met with, yet with slight variations; some, for example, of the layers of sand, clay, or

marl, may be wanting, one or more of them having thinned out and given place to others, or sometimes one of the layers first examined is observed to increase in thickness to the exclusion of other beds.

The term '*formation*,' which I have used in the above explanation, expresses in geology any assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we speak of stratified and unstratified, freshwater and marine, aqueous and volcanic, ancient and modern, metalliferous and non-metalliferous formations.

In the estuaries of large rivers, such as the Ganges and the Mississippi, we may observe, at low water, phenomena analogous to those of the drained lakes above mentioned, but on a grander scale, and extending over areas several hundred miles in length and breadth. When the periodical inundations subside, the river hollows out a channel to the depth of many yards through horizontal beds of clay and sand, the ends of which are seen exposed in perpendicular cliffs. These beds vary in their mineral composition, colour, and in the fineness or coarseness of their particles, and some of them are occasionally characterised by containing drift wood. At the junction of the river and the sea, especially in lagoons, nearly separated by sand bars from the ocean, deposits are often formed in which brackish and salt-water shells are included.

In Egypt, where the Nile is always adding to its delta by filling up part of the Mediterranean with mud, the newly deposited sediment is *stratified*, the thin layer thrown down in one season differing slightly in colour from that of a previous year, and being separable from it, as has been observed in excavations at Cairo, and other places.[1]

When beds of sand, clay, and marl, containing shells and vegetable matter, are found arranged in a similar manner in the interior of the earth, we ascribe a similar origin to them; and the more we examine their characters in minute detail, the more exact do we find the resemblance. Thus, for example, at various heights and depths in the earth, and often far from seas, lakes, and rivers, we meet with layers of rounded pebbles, composed of flint, limestone, granite, or other rocks, resembling the shingles of a sea-beach, or the gravel in a torrent's bed. Such layers of pebbles frequently alternate with others formed of sand or fine sediment, just as we may see in the channel of a river descending from hills bordering a coast, where the current sweeps down at one season coarse sand and gravel, while at another, when the

[1] See Principles of Geology, by the Author, Index, 'Nile,' 'Rivers,' &c.

waters are low and less rapid, fine mud and sand alone are carried seaward.[2]

If a stratified arrangement, and the rounded form of pebbles, are alone sufficient to lead us to the conclusion that certain rocks originated under water, this opinion is confirmed by the distinct and independent evidence of *fossils*, often very abundantly included in the earth's crust. By a *fossil* is meant any body, or the traces of the existence of any body, whether animal or vegetable, which has been buried in the earth by natural causes. Every stratum was the burial-ground of its time. Now the remains of animals, especially of aquatic species, are found almost everywhere imbedded, in stratified rocks, and sometimes, in the case of limestone, they are in such abundance as to constitute the entire mass of the rock itself. Shells and corals are the most frequent, and with them are often associated the bones and teeth of fishes, fragments of wood, impressions of leaves, and other organic substances. Fossil shells, of forms such as now abound in the sea, are met with, far inland, both near the surface, and at great depths below it. They occur at all heights above the level of the ocean, having been observed at elevations of more than 8,000 feet in the Pyrenees, 10,000 in the Alps, 13,000 in the Andes, and above 18,000 feet in the Himalaya.[3]

These shells belong mostly to marine testacea, but in some places exclusively to forms characteristic of lakes and rivers. Hence it is concluded that some ancient strata were deposited at the bottom of the sea, and others in lakes and estuaries.

Aërial or Æolian rocks were not much considered in the early days of Geology, but it is evident that they are forming at the present time over large surfaces of the earth, and that this was also the case in former ages. Changes take place on the surface of the earth which cannot be attributed to movements by water, and deposits accumulate which are also not referable to that agent. The vast deposits of loess in Eastern Asia are attributed to blown dust; the desert sands of rainless regions, the sand dunes of many coasts and inland areas, and of the sides of lakes, are due to removal, by air in movement, of substances which have often been entirely eroded by atmospheric action and sometimes by water. Soils and thick deposits, like the laterite of Hindostan, are the result of aërial changes upon the rocks. The collection of organic remains, both vegetable and animal, in masses, is often without the intervention of an aqueous agency, and coal and plant remains, and some

[2] See p. 20, fig. 7.
[3] Gen. Sir R. Strachey found Oolitic fossils at an altitude of 18,400 feet in the Himalaya.

collections of bones, were former examples. Volcanic ash is wafted far and wide by wind, and forms important deposits, many of which occurred on dry land. Frost destroys the rocks, and the relics are not aqueous in their origin. Moraine matter, the product of land glaciers, and the blocks carried by ice, or simply remaining as the relics of sub-aërial denudation, are considered under this group of aërial rocks. Many of these rocks assume the stratified form, and contain organic remains.

Volcanic rocks.—The third division of rocks which we may next consider are the volcanic, or those which have been produced at or near the surface, whether in ancient or modern times, by the action of subterranean heat, by water, and pressure, and these rocks are for the most part unstratified, and are devoid of fossils. They are more partially distributed than aqueous formations, at least in respect to horizontal extension. Among those parts of Europe where they exhibit characters not to be mistaken, I may mention not only Sicily and the country round Naples, but Auvergne, Velay, and Vivarais, now the departments of Puy-de-Dôme, Haute-Loire, and Ardèche, towards the centre and south of France, in which are several hundred conical hills having the forms of modern volcanos, with craters more or less perfect on many of their summits. Besides the parts of France above alluded to there are other countries, as the north of Spain, the south of Sicily, the Tuscan territory of Italy, the lower Rhenish provinces, Hungary, and many parts of Western America and Australia, where spent volcanos may be seen, still preserving, in many cases, a conical form, and having craters and often lava-streams connected with them. These cones are composed, moreover, of lava, sand, and ashes, similar to those of active volcanos. Streams of lava may sometimes be traced from the cones into the adjoining valleys, where they have choked up the ancient channels of rivers with solid rock, in the same manner as some modern flows of lava in Iceland have been known to do, the rivers either flowing beneath or cutting out a narrow passage on one side of the lava. Although none of these French volcanos have been in activity within the period of human history, their forms are often very perfect. Some, however, have been compared to the mere skeletons of volcanos, the rains and torrents having washed their sides, and removed all the loose sand and scoriæ, leaving only the harder and more solid materials. By this erosion, and by earthquakes, their internal structure has occasionally been laid open to view, in fissures and ravines; and we then behold not only many successive beds and masses of lava, sand, and porous scoriæ, but also perpendicular walls or *dikes*, as they are

called, of volcanic rock, which have burst through the other materials. Such dikes are also observed in the structure of Vesuvius, Etna, and other active volcanos.

There are also other rocks in almost every country in Europe, which we infer to be of igneous origin, although they do not form hills with cones and craters. Thus, for example, we feel assured that the rock of Staffa, and that of the Giant's Causeway, called basalt, is volcanic, because it agrees in its columnar structure and mineral composition with streams of lava which we know to have flowed from the craters of recent volcanos. We find also similar basaltic and other igneous rocks associated with beds of *tuff* in various parts of the British Isles and also forming *dikes*, such as have been spoken of; and some of the strata through which they cut are occasionally altered at the point of contact, as if there had been an exposure to the intense heat of melted matter.

The absence of cones and craters, and long narrow streams of superficial lava, in England and many other countries is partly to be attributed to the eruptions having been sub-marine, just as a considerable proportion of volcanos in our own times burst out beneath the sea: or the eruption may have been from fissures in the earth's surface. But this question must be enlarged upon more fully in the chapters on igneous rocks, in which it will also be shown, that as different sedimentary formations, containing each their characteristic fossils, have been deposited at successive periods, so also volcanic sand and scoriæ have been thrown out, and lavas have flowed over the land or bed of the sea, or have been injected into fissures, at many different epochs; so that the igneous as well as the aqueous and aërial rocks may be classed as a chronological series of monuments, throwing light on a succession of events in the history of the earth.

Plutonic rocks.—If we examine a large portion of a continent, especially if it contain within it a lofty mountain range, we rarely fail to discover two other classes of rocks, very distinct from either of those above alluded to, and which we can neither assimilate to deposits such as are now accumulated in lakes or seas nor to those generated by ordinary volcanic action. The members of both these classes of rocks agree in being highly crystalline and destitute of organic remains. The rocks of one class have been called plutonic, comprehending all the granites, syenites, and certain porphyries, which are allied in some of their characters to volcanic rocks. The members of the other class are stratified or foliated, and often slaty. They are the *crystalline schists*, or metamorphic rocks, in which group are included gneiss, micaceous schist, hornblende-schist, statuary

marble, the finer kinds of roofing slate, and other rocks afterwards to be described.

As it is admitted that nothing strictly analogous to these crystalline rocks can now be seen in the progress of formation on the earth's surface, it will naturally be asked on what data we can find a place for them in a system of classification founded on the origin of rocks. It may be stated as the result of careful study that the various kinds of rocks, such as granite and syenite, which constitute the plutonic family, are of igneous or aqueo-igneous origin, and have been formed under great pressure, at a considerable depth in the earth, or sometimes, perhaps, under a certain weight of incumbent ocean. Like the lava of volcanos, they have been melted, and have afterwards cooled and crystallised, but with extreme slowness, and under conditions very different from those producing such volcanic rocks. Hence they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases and steam give rise in ordinary lava.

Metamorphic crystalline rocks.—The last great division of rocks includes the crystalline strata and slates, or schists, called gneiss, mica-schist, clay-slate, chlorite-schist, marble, and the like, the origin of which is more doubtful than that of the other classes. They rarely contain any pebbles, or sand, or scoriæ, or angular pieces of imbedded stone, or traces of organic bodies, and they are often as crystalline as granite, yet are divided into beds, corresponding in form and arrangement to those of sedimentary formations, and are therefore said to be stratified. The beds sometimes consist of an alternation of minerals varying in colour, composition, and thickness, precisely as we see in stratified fossiliferous deposits. According to the Huttonian theory, which I adopt as the most probable, and which will be afterwards more fully explained, the materials of these rocks were originally deposited from water in the form of sediment, but they were subsequently so altered by heat, chemical action, and pressure, as to assume a new texture, and often mineral composition. It is demonstrable, in some cases at least, that such a complete conversion has actually taken place, fossiliferous strata having exchanged an earthy for a highly crystalline texture for a distance of a quarter of a mile from their contact with granite. In some cases dark limestones, replete with shells and corals, have been turned into white statuary marble, and hard clays, containing vegetable or other

remains, into slates called mica-schist or hornblende-schist, every vestige of the organic bodies having been obliterated.

Heated water permeating stratified masses and great pressure have no doubt played their part in producing the schistose and foliated texture and other changes, and it is clear that the transforming influence has often pervaded entire mountain masses of strata.

In accordance with the hypothesis above alluded to, I proposed in the first edition of the 'Principles of Geology' (1833) the term 'Metamorphic' for the altered strata, a term derived from μετά, meta, *trans*, and μορφή, morphe, *forma*.

This metamorphism may be local or regional, and was more intense in the earlier geological periods than subsequently.

Hence there are five classes of rocks considered in reference to their origin—the aqueous, the aërial, the volcanic, the plutonic, and the metamorphic. In the course of this work it will be shown that portions of each of these five distinct classes have originated at successive periods of the world's history.

The aqueous and aërial classes have been produced by energies acting on the outside of the globe, and the volcanic and plutonic have been produced by internal energies. The metamorphic rocks have had a double origin, so far as their producing agents are concerned.

The term plutonic applies to the crystalline rocks, like granite and syenite, which differ in degree from the volcanic rocks. The term 'hypogene' was proposed in the 'Principles of Geology' (ed. i. vol. iii.), a word derived from ὑπό, under, and γίνομαι, to be, or be born, to indicate that the crystalline plutonic rocks are *nether* formed rocks, and which have not assumed their present form and structure at the surface. They never simply repose on volcanic or sedimentary rocks, and can be traced beneath everything, and they underlie all other rocks.

But metamorphic rocks of the advanced type of gneiss and mica schist do not appear to have necessarily been formed at great depths, or under the conditions which granite required for its genesis. Hence the term hypogene is hardly applicable to them. The term hypogene action has lately been aptly employed by Professor A. Geikie[4] to express the changes within the earth caused by original internal heat and chemical action, of which the intrusion of granites as eruptive rocks and metamorphism on a grand scale are examples.

From what has now been said, the reader will understand that each of the great classes of rocks may be studied under two distinct points of view; first, they may be studied simply as

[4] Text-book of Geology (1882), p. 196.

mineral masses deriving their origin from particular causes, and having a certain chemical composition, form, and position in the earth's crust, or other characters, both positive and negative, such as the presence or absence of organic remains. In the second place, the rocks of each class may be viewed as a grand chronological series of monuments, attesting a succession of events in the former history of the globe and of its living inhabitants.

I shall accordingly proceed to treat of each class of rocks; first, in reference to those characters which are not chronological, and then in particular relation to the several periods when they were formed.

CHAPTER II.

AQUEOUS ROCKS—THEIR COMPOSITION AND FORMS OF STRATIFICATION.

Mineral composition of strata—Siliceous rocks—Argillaceous—Calcareous—Gypsum—Loess—Coal—Soil—Ice-borne rocks—Forms of stratification—Original horizontality—Thinning out—Diagonal arrangement—Ripple mark.

In pursuance of the arrangement explained in the last chapter, we shall begin by examining the aqueous and aërial or sedimentary rocks, which are for the most part distinctly stratified, and often contain fossils. We may first study them with reference to their mineral composition, external appearance, position, mode of origin, organic contents, and other characters which belong to them as sedimentary formations, independently of their age, and we may afterwards consider them chronologically or with reference to the successive geological periods when they originated.

I have already given an outline of the data which led to the belief that the stratified and fossiliferous rocks were originally, with rare exceptions, deposited under water; but, before entering into a more detailed investigation, it will be desirable to say something of the ordinary materials of which such strata are composed. These may be said to belong principally to three divisions—the siliceous, the argillaceous, and the calcareous, which are formed respectively of flint, clay, and carbonate of lime. Of these, the siliceous are chiefly made up of sand, or flinty grains; the argillaceous, or clayey, of a mixture of siliceous matter with certain proportions of aluminous earth; and, lastly, the calcareous rocks or limestones, of carbonic acid and lime, sometimes with carbonate of magnesia.

Siliceous and arenaceous rocks.—To speak first of the sandy division : beds of loose sand are frequently met with, of which the grains consist entirely of silica, which term comprehends all purely siliceous minerals, as quartz and common flint.[1] The siliceous grains in sand are usually more or less rounded, as if by the action of running water. Sandstone is an aggregate of such grains, which often cohere together without any visible cement, but more commonly are bound together by a slight quantity of siliceous or calcareous matter, or by oxide of iron, clay or felspar.

Amongst the siliceous rocks, the result of deposition of fragments of previously existing formations, are gravels, river sands, and sandstones, which may be flagstones, which are thin bedded and split along the lines of stratification ; freestones, which are not divided by laminæ, and grits, which have the grains large and visible to the eye ; breccias, or angular masses of sandstone more or less included in a common uniting material ; conglomerates, with rounded pebbles included in a calcareous or siliceous matrix ; arkoses or granitic sandstones ; micaceous sandstones with thin silvery plates of mica arranged in layers paralled to the planes of stratification, giving a slaty texture to the rock. Greywacke, a hard grey or dark coloured rock, is a collection of rounded or sub-angular grains of quartz felspar, slate, &c., cemented by a paste which may be siliceous, clayey, felspathic or calcareous, and even anthracitic. This rock, often ripple-marked and sun-cracked, accumulated in running water in ancient geological periods. In nature there is every intermediate gradation from perfectly loose sand to the hardest sandstone.

Argillaceous rocks.—Clay, strictly speaking, is a mixture of silica or flint with a large proportion, usually about one-fourth, of alumina ; but in common language, any earth which possesses sufficient ductility, when kneaded up with water, to be fashioned like paste by the hand, or by the potter's lathe, is called a *clay* ; and such clays vary greatly in their composition, and are, in general, nothing more than mud derived from the decomposition or wearing down of rocks. The purest clay found in nature is porcelain clay, or kaolin, which results from the decomposition of granite. *Shale* has also the property, like clay, of becoming plastic in water : it is a more solid form of clay, or argillaceous matter, condensed by pressure. It always divides into more or less regular laminæ.

Flinty slate, or Lydian-stone, and clay-slate are forms of clay which have undergone changes from the infiltration of chemical solutions. Mud-stone is a sandy, clayey rock. Fullers' earth is a

[1] For a description of all usual rock-making minerals see the Appendix.

greenish or brownish earth, soft and unctuous, with a shining streak, crumbling into mud in water. Brick clay is any clay, loam, or earth from which bricks can be made, and is an impure clay as a rule, with a good deal of iron. Gannister is a siliceous rock with clay found in the lower coal measures. Fire clay underlies coal seams, and contains but little iron and alkalies.

One general character of all argillaceous rocks is to give out a peculiar earthy odour when breathed upon, which is a test of the presence of aluminous earth, although it does not belong to the pure substance, but is apparently due to its combination with oxide of iron.

Calcareous rocks.—This division comprehends those rocks which, like chalk, are composed chiefly of lime and carbonic acid. Shells and corals are also formed of the same compounds, with the addition of animal matter. To obtain pure lime it is necessary to calcine these calcareous substances, that is to say, to expose them to heat of sufficient intensity to drive off the carbonic-acid gas. White chalk is sometimes nearly pure carbonate of lime; and this rock, although usually in a soft and earthy state, is occasionally sufficiently solid to be used for building, and even passes into a compact stone, the separate parts of which are so minute as not to be distinguishable from each other by the naked eye.

The carboniferous limestone and the chalk may be taken as examples of organic limestones and coral rock and encrinital limestone also. Shell marl is a soft earthy deposit formed of shells, sand, and clay. It may become compact as in many fresh-water or lacustrine deposits.

Many limestones are made up entirely of minute fragments of shells and coral. Others are of calcareous sand cemented together, and are called 'calcareous sandstones;' but that term is more properly applied to a rock in which the grains are partly calcareous and partly siliceous, or to quartzose sandstones, having a cement of carbonate of lime.

The variety of limestone called *oolite* is composed of numerous small egg-like grains, resembling the roe of a fish, each of which has usually a small fragment of some organism or a grain of mineral as a nucleus, around which concentric layers of calcareous matter have accumulated. *Pisolite limestone* has the oolitic grains of considerable size.

Any limestone which is sufficiently hard to take a fine polish is called *marble*. Many of these are fossiliferous; but statuary marble, which is also called saccharoid limestone, from having a texture resembling that of loaf-sugar, is devoid of fossils, and is in many cases a member of the metamorphic series.

Siliceous limestone is an intimate mixture of carbonate of lime and silica, and is harder in proportion as the flinty matter predominates.

The presence of carbonate of lime in a rock may be ascertained by applying, to the surface, a drop of diluted nitric or hydrochloric acid; effervescence and the escape of carbonic-acid gas result. Without the aid of this test, the most experienced eye cannot always detect the presence of the mineral.

The above-mentioned three classes of rocks—the siliceous, argillaceous, and calcareous—pass continually into each other, and rarely occur in a perfectly separate and pure form. Thus it is an exception to the general rule to meet with a limestone as pure as ordinary white chalk, or with clay as aluminous as that used in Cornwall for porcelain, or with sand so entirely composed of siliceous grains as the white sand of Alum Bay in the Isle of Wight, employed in the manufacture of glass, or sandstone so pure as the grit of Fontainebleau, used for pavement in France. More commonly we find sand and clay, or clay and marl, intermixed in the same mass. When the sand and clay are each in considerable quantity, the mixture is called *loam*. If there is much calcareous matter in clay it is called *marl*; but this term has unfortunately been used so vaguely, as often to be very ambiguous. It has been applied, for example, to substances in which there is no lime; as, to that red loam usually called red marl in certain parts of England. Agriculturists were in the habit of calling any soil a marl which, like true marl, fell to pieces readily on exposure to the air. Hence arose the confusion of using this name for soils which, consisting of loam, were easily worked by the plough, though devoid of lime.

Marl slate bears the same relation to marl which shale bears to clay, being a calcareous shale. It is very abundant in some countries, as in the Swiss Alps. Argillaceous or marly limestone is also of common occurrence.

There are few other kinds of rock which enter so largely into the composition of sedimentary strata as to make it necessary to dwell here on their characters. I may, however, mention two others—magnesian limestone or dolomite, and gypsum. *Magnesian limestone* is composed of carbonate of lime and carbonate of magnesia; the proportion of the latter amounting in come cases to nearly one-half. It effervesces much more slowly and feebly with acids than common limestone. In England this rock is generally of a yellowish colour; but it varies greatly in mineralogical character, passing from an earthy state to a white compact stone of great hardness. *Dolomite*, so common

in many parts of Germany and France, is also a variety of magnesian limestone, usually of a granular texture.

Gypsum is a mineral which is often found in great masses or rocks. It is a sulphate of lime, and is usually a soft whitish-yellow rock, with a texture resembling that of loaf-sugar, but sometimes it is entirely composed of lenticular crystals. Anhydrous gypsum is a rare variety, into which water does not enter as a component part. *Gypseous marl* is a mixture of gypsum and marl. *Alabaster* is a granular and compact variety of gypsum found in masses large enough to be used in sculpture and architecture. It is sometimes a pure snow-white substance, as that of Volterra in Tuscany, well known as being carved for works of art in Florence and Leghorn. It is a softer stone than marble, and more easily wrought.

Aërial or Æolian deposits are necessarily fragmental, and wind has been the moving and depositing agent, and by frequently acting with moving solid bodies like sand, has produced the deposits themselves. Blown sands, desert sands, and dust are of great geological importance and form deep strata. The loess, a yellowish calcareous clay in Eastern Asia, is a vast deposit containing land shells and bones of land animals; it is the result of the constant blowing of dust off rocks in one direction, and it has accumulated to a thickness of 1,500 feet and more, and is found at an altitude of 6,000 feet.

Many rocks which have been formed by the mechanical and chemical action of the atmosphere are Æolian, such as many soils. Laterite is gneiss altered *in situ*, and it remains on the surface as an aërial rock. Probably coal, peat, and many strata which have grown as it were in place, and have accumulated without the aid of moving water, should be called aërial, and also the *débris* at the base of rocks and precipices.

Ice-borne deposits.—The moraines of ancient and modern glaciers are examples of deposits which present themselves to the geologist, and they occupy a position between the aqueous and aërial class of rocks.

It is now necessary to consider the forms of the layering of these deposits.

Forms of stratification.—A series of strata sometimes consists of one of the above rocks, sometimes of two or more in alternating beds.

Thus, for example, in the coal districts of England, we often pass through several beds of sandstone, some of finer, others of coarser grain, some white, others of a dark colour, and below these, layers of shale and sandstone or beds of shale, divisible into leaf-like laminæ, and containing beautiful impressions of

plants. Then again we meet with beds of pure and impure coal, alternating with shales and sandstones, and underneath the whole, perhaps, are calcareous strata or beds of limestone, filled with corals and marine shells, each bed distinguishable from another by certain fossils, or by the abundance of particular species of shells or zoophytes.

This alternation of different kinds of rock produces the most distinct stratification; and we often find beds of limestone and marl, conglomerate and sandstone, sand and clay, recurring again and again, in nearly regular order, throughout a series of many hundred strata. The causes which may produce these phenomena are various, and may be either changes in the nature and degree of fineness of the material deposited, or interruptions in the regular course of deposition, when the layer first formed may have time to consolidate before the next layer is spread over it, and so bring about an imperfect adhesion between successive strata of the same composition. Thus, rivers flowing into lakes and seas are charged with sediment, varying in quantity, composition, colour, and grain according to the seasons; the waters are sometimes flooded and rapid, at other periods low and feeble. Different tributaries, also, draining peculiar countries and soils, and therefore charged with peculiar sediment, are swollen at distinct periods, but all these different kinds of sediment will be deposited successively over the same area. The waves of the sea also and currents undermine the cliffs during wintry storms, and sweep away the materials into the deep, after which a season of tranquillity succeeds, when nothing but the finest mud is spread by the movements of the ocean over the same submarine area.

It is not the object of the present work to give a description of these operations, repeated as they are year after year and century after century; but I may explain by way of illustration the manner in which some micaceous sandstones have originated, namely, those in which we see thin layers of mica dividing layers of fine quartzose sand. I observed this arrangement of materials in recent mud deposited in the estuary of La Roche St. Bernard in Britanny, at the mouth of the Loire. The surrounding rocks are of gneiss, which, by its waste, supplies the mud: when this dries, at low water, it is found to consist of brown laminated clay, divided by thin seams of mica. The separation of the mica in this case, or in that of micaceous sandstones, may be thus understood. If we take a handful of quartzose sand, mixed with mica, and throw it into a clear running stream, we see the materials immediately sorted by the moving water, the grains of quartz falling almost directly to the

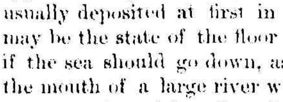
bottom, while the plates of mica take a much longer time to sink through the water, and are carried farther down the stream. At the first instant the water is turbid, but almost immediately the flat surfaces of the plates of mica are seen all alone, reflecting a silvery light as they descend slowly, to form a distinct micaceous lamina. The mica is the heavier mineral of the two, but it remains a longer time suspended in the fluid, owing to its greater extent of surface. It is easy, therefore, to perceive that where such mud is acted upon by a river or tidal current, the thin plates of mica will be carried farther, and not deposited in the same places as the grains of quartz; and since the force and velocity of the stream varies from time to time, layers of mica or of sand will be thrown down successively on the same area.

Original horizontality. It is said generally that the upper and under surfaces of strata, or the 'planes of stratification,' are parallel. Although this is not strictly true, they make an approach to parallelism, for the same reason that sediment is usually deposited at first in nearly horizontal layers, whatever may be the state of the floor on which the deposit rests. Yet if the sea should go down, as when there is very low tide, near the mouth of a large river where a delta has been forming, we see extensive plains of mud and sand laid dry, which, to the eye, appear perfectly level, although, in reality, they slope gently from the land towards the sea.

This tendency in newly formed strata to assume a horizontal position arises principally from the motion of the water, which forces along particles of sand or mud at the bottom, and causes them to settle in hollows or depressions where they are less exposed to the force of a current than when they are resting on elevated points. The velocity of the current and the motion of the superficial waves diminish from the surface downwards, and are least in those depressions where the water is deepest.

A good illustration of the principle here alluded to may be sometimes seen in the neighbourhood of a volcano, when a section, whether natural or artificial, has laid open to view a succession of various-coloured layers of sand and ashes, which have fallen in showers upon uneven ground. Thus let A B (fig. 1) be two ridges with an intervening valley. These original inequalities of the surface have been gradually effaced by beds of sand and ashes, c, d, e, the surface at e being quite level. It will be seen that, although the materials of the first layers have accommodated themselves in a great

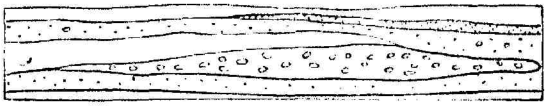
Fig. 1.



degree to the shape of the ground A B, yet each bed is thickest at the bottom. At first a great many particles would be carried by their own gravity down the steep sides of A and B, and others would afterwards be blown by the wind as they fell off the ridges, and would settle in the hollow, which would thus become more and more effaced as the strata accumulated from *c* to *e*. Now, water in motion can exert this levelling power on similar materials more easily than air, for almost all stones lose in water more than a third of the weight which they have in air, the specific gravity of rocks being in general as 2½ when compared to that of water, which is estimated at 1. But the buoyancy of sand or mud would be still greater in the sea, as the density of salt water exceeds that of fresh.

Yet, however uniform and horizontal may be the surface of new deposits in general, there are still many disturbing causes, such as eddies in the water, and currents moving first in one and then in another direction, which frequently cause irregularities. We may sometimes follow a bed of limestone, shale, or sandstone for a distance of many hundred yards continuously, but we generally find at length that each individual stratum

Fig. 2.



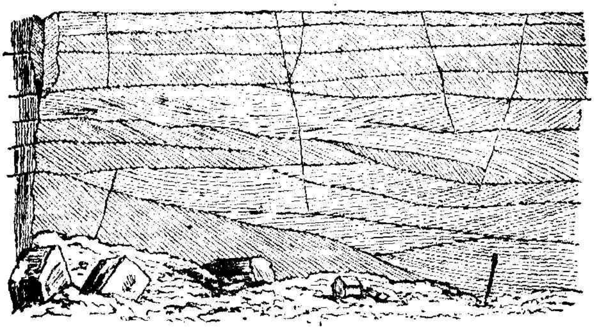
Section of strata of sandstone, grit, and conglomerate.

thins out, and allows the beds which were previously above and below it to meet. If the materials are coarse, as in grits and conglomerates, the same beds can rarely be traced many yards without varying in size, and often rapidly thinning out and coming to an end. (See fig. 2.)

Diagonal or cross stratification.—There is also another phenomenon of frequent occurrence. We find a series of larger strata, each of which is composed of a number of minor layers placed obliquely to the general planes of stratification. To this diagonal arrangement the name of 'false or cross bedding' has been given. Thus in the annexed section (fig. 3) we see many beds of loose sand, yellow and brown, and some of the principal planes of stratification are nearly horizontal. But the greater part of the subordinate laminæ do not conform to these planes, but have often a steep slope, the inclination being sometimes towards opposite points of the compass. When the sand is loose and incoherent, as in the case here represented, the deviation

from parallelism of the slanting laminæ cannot possibly be accounted for by any rearrangement of the particles acquired during the consolidation of the rock. In what manner, then, can such irregularities be due to original deposition? We must

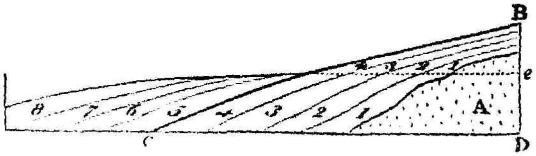
Fig. 3.



Diagonal bedding in Great Oolite. After Jukes-Brown.

suppose that at the bottom of shallow seas, as well as in the beds of rivers, the motions of waves, currents, and eddies often cause mud, sand, and gravel to be thrown down in heaps on particular spots instead of being spread out uniformly over a wide area. Sometimes, when banks are thus formed, currents may cut passages through them, just as a river forms its bed. Suppose

Fig. 4.



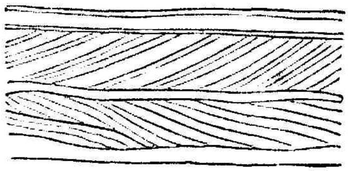
the bank A (fig. 4) to be thus formed with a steep sloping side, and, the water being in a tranquil state, the layer of sediment No. 1 is thrown down upon it, conforming nearly to its surface. Afterwards the other layers, 2, 3, 4, may be deposited in succession, so that the bank B C D is formed. If the current then increases in velocity, it may cut away the upper portion of this mass down to the dotted line *e*, and deposit the materials thus removed farther on, so as to form the layers 5, 6, 7, 8. We have

now the bank B C D E (fig. 5), of which the surface is almost level, and on which the nearly horizontal layers, 9, 10, 11, may

Fig. 5.

then accumulate. It was shown in fig. 3 that the diagonal layers of successive strata may sometimes have an opposite slope. This is well seen in some cliffs of loose sand on the Suffolk coast. A portion of one of these is represented in fig. 6, where the layers, of which there are about six in the thickness of an inch, are composed of quartzose grains. This arrangement may have been due to the altered direction of the tides and currents in the same place.

Fig. 6.

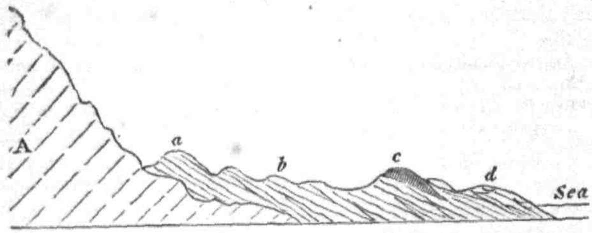


Cliff between Mismer and Dunwich.

The description above given of the slanting position of the minor layers constituting a single stratum, is in certain cases applicable on a much grander scale to masses several hundred feet thick, and many miles in extent. A fine example may be seen at the base of the Maritime Alps near Nice. The mountains here terminate abruptly in the sea, so that a depth of one hundred fathoms is often found within a stone's throw of the beach, and sometimes a depth of 3,000 feet within half a mile. But at certain points strata of sand, marl, or conglomerate intervene between the shore and the mountains, as in the section (fig. 7), where a vast succession of slanting beds of gravel and sand may be traced from the sea to Monte Calvo, a distance of no less than 9 miles in a straight line. The dip of these beds is remarkably uniform, being always southward or towards the Mediterranean, at an angle of about 25°. They are exposed to view in nearly vertical precipices, varying from 200 to 600 feet in height, which bound the valley through which the river Magnan flows. Although, in a general view, the strata appear to be parallel and uniform, they are nevertheless found, when examined closely, to be wedge-shaped, and to thin out when followed for a few hundred feet or yards, so that we may suppose them to have been thrown down originally upon the side of a steep bank where a river or

alpine torrent discharged itself into a deep and tranquil sea, and formed a delta, which advanced gradually from the base of Monte Calvo to a distance of 9 miles from the original

Fig. 7.



Section from Monte Calvo to the sea by the valley of Magnan, near Nice.

A. Dolomite and sandstone of Mesozoic age ?
a, b, d. Beds of gravel and sand.
c. Fine marl and sand of Ste. Madeleine, with marine (Pliocene) shells.

shore. If subsequently this part of the Alps and bed of the sea were raised 700 feet, the delta may have emerged; a deep channel may then have been cut through it by the river, and the coast may at the same time have acquired its present configuration.

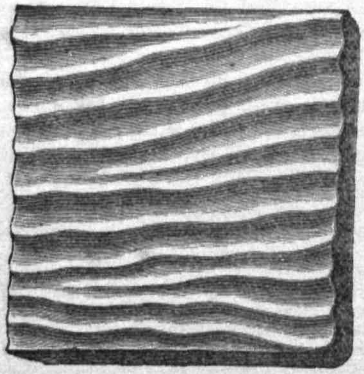
It is well known that the torrents and streams which now descend from the alpine declivities to the shore bring down annually, when the snow melts, vast quantities of shingle and sand, and then, as they subside, fine mud, while in summer they are nearly or entirely dry; so that it may be safely assumed that deposits like those of the valley of the Magnan, consisting of coarse gravel alternating with fine sediment, are still in progress at many points, as, for instance, at the mouth of the Var. They must advance upon the Mediterranean in the form of great shoals terminating in a steep talus; such being the original mode of accumulation of all coarse materials conveyed into deep water, especially where they are composed in great part of pebbles, which cannot be transported to indefinite distances by currents of moderate velocity. By inattention to facts and inferences of this kind, a very exaggerated estimate has sometimes been made of the supposed depth of the ancient ocean. There can be no doubt, for example, that the strata *a*, fig. 7, or those nearest to Monte Calvo, are older than those indicated by *b*, and these again were formed before c; but the vertical depth of gravel and sand in any one place cannot be proved to amount even to 1,000 feet, although it may perhaps

be much greater, yet probably never exceeding at any point 3,000 or 4,000 feet. But were we to assume that all the strata were once horizontal, and that their present dip or inclination was due to subsequent movements, we should then be forced to conclude, that a sea several miles deep had been filled up with alternate layers of mud and pebbles thrown down one upon another.

In the locality now under consideration, situated a few miles to the west of Nice, there are many geological data, the details of which cannot be given in this place, all leading to the opinion that when the deposit of the Magnan was formed, the shape and outline of the alpine declivities and the shore greatly resembled what we now behold at many points in the neighbourhood. That the beds *a*, *b*, *c*, *d*, are of comparatively modern date is proved by this fact, that in seams of loamy marl intervening between the pebbly beds are fossil shells, half of which belong to species now living in the Mediterranean.

Ripple marks.—The ripple marks, so common on the surface of sandstones of all ages (see fig. 8), and which are so often seen on the sea-shore at low tide, seem to originate in the drifting of materials along the bottom of the water, in a manner very

Fig. 8.



Slab of ripple-marked (New Red) sandstone, from Cheshire.

similar to that which may explain the inclined layers above described. This ripple is not entirely confined to the beach between high and low water-mark, but is also produced on sands which are constantly covered by water. Similar undulating

ridges and furrows may also be sometimes seen on the surface of drift snow and blown sand.

Ripple marks are usually an indication of a sea-beach, or of water from 6 to 10 feet deep, for the agitation caused by waves even during storms extends to no great depth. To this rule, however, there are some exceptions, and recent ripple marks have been observed at a depth of 60 or 70 feet. It has also been ascertained that currents or large bodies of water in motion may disturb mud and sand at a depth of 300 or even 450 feet.[2] Beach ripple, however, may usually be distinguished from current ripple by frequent changes in its direction. In a slab of sandstone, not more than an inch thick, the furrows or ridges of an ancient ripple may often be seen in several successive laminæ to run towards different points of the compass.

CHAPTER III.

ARRANGEMENT OF FOSSILS IN STRATA—FRESHWATER AND MARINE.

Successive deposition indicated by fossils—Limestones formed of corals and shells—Proofs of gradual increase of strata derived from fossils—Slow rate of accumulation—Serpula attached to Spatangus—Wood bored by Teredina—Tripoli formed of infusoria—Chalk derived principally from organic bodies—*Distinction of freshwater from marine formations*—Genera of freshwater and land shells—Rules for recognising marine testacea—Gyrogonite and Chara—Freshwater fishes—Alternation of marine and freshwater deposits—Lym-Fiord—Deep-sea deposits.

HAVING in the last chapter considered the forms of stratification so far as they are determined by the arrangement of inorganic matter, we may now turn our attention to the manner in which organic remains are distributed through stratified deposits. We should often be unable to detect any signs of stratification or of successive deposition, if particular kinds of fossils did not occur here and there at certain depths of the mass. At one level, for example, univalve shells of some one or more species predominate; at another, bivalve shells; and at a third, corals; while in some formation we find layers of vegetable matter, commonly derived from land plants, separating strata.

It may appear inconceivable to a beginner how mountains, several thousand feet thick, can have become full of fossils from top to bottom; but the difficulty is removed, when he reflects on the origin of stratification, as explained in the last chapter, and

[2] Darwin, Volc. Islands, p. 134.

allows sufficient time for the accumulation of sediment. He must never lose sight of the fact that, during the process of deposition, each separate layer was once the uppermost, and immediately in contact with the water in which aquatic animals lived. Each stratum, in fact, however far it may now lie beneath the surface, was once in the state of shingle, or loose sand or soft mud at the bottom of the sea, in which shells and other bodies easily became enveloped.

Rate of deposition indicated by fossils.—By attending to the nature of these remains, we are often enabled to determine whether the deposition was slow or rapid, whether it took place in a deep or shallow sea, near the shore or far from land, and whether the water was salt, brackish or fresh. Some limestones consist almost exclusively of corals, and in many cases it is evident that the present position of each fossil zoophyte has been determined by the manner in which it grew originally. The axis of the coral, for example, if its natural growth is erect, still remains at right angles to the plane of stratification. If the stratum be now horizontal, the round spherical heads of certain species continue uppermost, and their points of attachment are directed downwards. This arrangement is sometimes repeated throughout a great succession of strata. From what we know of the growth of similar zoophytes in modern reefs, we infer that the rate of increase was extremely slow, and some of the fossils must have flourished for years, like forest trees, before they attained so large a size. During these ages, the water must have been clear and transparent, for such corals cannot live in turbid water.

Fig. 9.

Fossil *Gryphæa*, covered both on the outside and inside with fossil serpulæ.

In like manner, when we see thousands of full-grown shells dispersed everywhere throughout a long series of strata, we cannot doubt that time was required for the

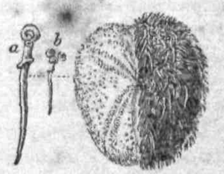
multiplication of successive generations; and the evidence of slow accumulation is rendered more striking from the proofs, so often discovered, of fossil bodies having lain for a time on the floor of the ocean after death before they were imbedded in sediment. Nothing, for example, is more common than to see fossil oysters in clay, with serpulæ, or barnacles (acorn-shells), or corals, and other creatures attached to the inside of the valves, so that the mollusk was certainly not buried in argillaceous mud the moment it died. There must have been an interval during which it was still surrounded with clear water, when the creatures whose remains now adhere to it grew from an embryonic to a mature state. Attached shells which are merely external, like some of the serpulæ (*a*) in fig. 9, may often have grown upon an oyster or other shell while the animal within was still living; but if they are found on the inside, it could only happen after the death of the inhabitant of the shell which affords the support. Thus, in fig. 9 it will be seen that two serpulæ have grown on the interior, one of them exactly on the place where the adductor muscle of the *Gryphæa* (a kind of oyster) was fixed.

Some fossil shells, even if simply attached to the *outside* of others, bear full testimony to the conclusion above alluded to, namely, that an interval elapsed between the death of the creature to whose shell they adhere and the burial of the same in mud or sand. The sea-urchins, or *Echini*, so abundant in white chalk, afford a good illustration. It is well known that these animals, when living, are invariably covered with spines supported by rows of tubercles. These last are only seen after the

Fig. 10.

Serpula attached to a fossil *Micraster*, from the chalk.

Fig. 11.



Recent *Spatangus* with the spines removed from one side.
b. Spine and tubercles, nat. size.
a. The same magnified.

death of the sea-urchin, when the spines have dropped off. In fig. 11 a living specimen of *Spatangus*, common on our coast, is represented with one half of its shell stripped of the spines. In fig. 10 a fossil of the genus *Micraster* found in the white chalk of England shows the naked surface which the individuals of this species exhibited when denuded of their spines. The

full-grown *Serpula*, therefore, which now adheres externally, could not have begun to grow till the *Micraster* had died, and the spines became detached.

Fig. 12.

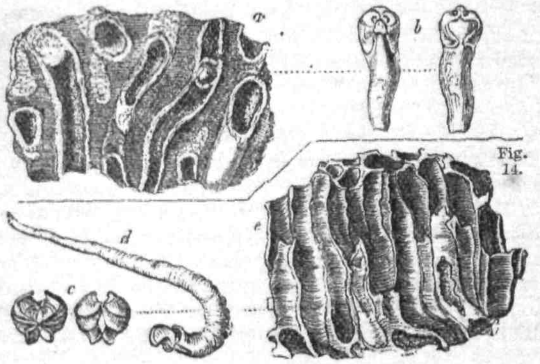
a. Ananchytes from the chalk with lower valve of *Crania* attached, ½.
b. Upper valve of *Crania* detached.

Now the series of events here attested by a single fossil may be carried a step farther. Thus, for example, we often meet with a sea-urchin (*Ananchytes*) in the chalk (see fig. 12), which has the lower valve of a *Crania*, a genus of *Brachiopoda*, fixed to it. The upper valve (*b*, fig. 12) is almost invariably wanting, though occasionally found in a perfect state of preservation in white chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young *Crania* adhered to the bared shell, grew and perished in its turn; after which the upper valve was separated from the lower before the *Ananchytes* became enveloped in chalky mud. The rate of accumulation of the chalk must therefore have been very slow.

It may be well to mention one more illustration of the manner in which single fossils may sometimes throw light on a former state of things, both in the bed of the ocean and on some adjoining land. We meet with many fragments of wood bored by ship-worms, at various depths in the clay on which London is built. Entire branches and stems of trees, several feet in length, are sometimes found drilled all over by the holes of these borers, the tubes and shells of the mollusk still remaining in the cylindrical hollows. In fig. 14, *e*, a representation is given of a piece of recent wood pierced by the *Teredo navalis*, or common ship-worm, which destroys wooden piles and ships. When the cylindrical tube *d* has been extracted from the wood, the valves are seen at the larger or anterior extremity, as shown at *c*. In like manner, a piece of fossil wood (*a*, fig. 13) has been perforated by a kindred but distinct genus, the *Teredina* of Lamarck. The calcareous tube of this mollusk was united and as it were soldered on to the valves of the shell (*b*), which therefore cannot be detached from the tube, like the valves of the recent *Teredo*. The wood in this fossil specimen is now converted into a stony mass, a mixture of clay and lime; but it must once have been buoyant and floating in the sea, when the *Teredinæ* lived upon, and perforated it. Again, before the infant colony settled upon the drift wood, part of a tree must have been floated down to the sea by a river, uprooted, perhaps, by a flood, or torn off and cast into the waves by the wind; and

thus our thoughts are carried back to a prior period, when the tree grew for years on dry land, enjoying a fit soil and climate.

Fig. 13.



Fossil and recent wood drilled by perforating Mollusca.

Fig. 13. *a.* Fossil wood from London clay, bored by *Teredina*, ½.
b. Shell and tube of *Teredina personata*, the right-hand figure the ventral, the left the dorsal view.

Fig. 14. *e.* Recent wood bored by *Teredo*, ½.
d. Shell and tube of *Teredo navalis*, from the same.
c. Anterior and posterior view of the valves of same detached from the tube, nat. size.

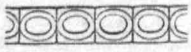
The present rate of accumulation of deep sea sediment is exceedingly slow, as is proved by the growths of coral that occur on electric cables. The corals grow at great depths very much quicker than the accumulation of the foraminiferal oaze.[1] But rapid accumulation of some sediments must have taken place formerly, for tree stems standing erect are found in strata of coal, sand, and grit which gathered around them.

It has been already remarked that there are rocks in the interior of continents, at various depths in the earth, and at great heights above the sea, almost entirely made up of the remains of zoophytes and testacea. Such masses may be compared to modern oyster-beds and coral-reefs; and, like them, the rate of increase must have been extremely gradual. But there are a variety of stone deposits in the earth's crust, now proved to have been derived from plants and animals of which the organic origin was not suspected until of late years, even by naturalists. Great surprise was therefore created some years since by the discovery of Professor Ehrenberg, of Berlin, that a certain kind of

[1] Duncan, Proc. Roy. Soc. vol. xxvi. p. 133, 1877.

siliceous stone, called tripoli, was entirely composed of millions of the remains of organic beings, which were formerly referred to microscopic Infusoria, but which are now admitted to be plants. They abound in rivulets, lakes, and ponds in England and other countries, and are termed Diatomaceæ by those naturalists who believe in their vegetable origin. The subject alluded to has long been well known in the arts, under the name of Infusorial Earth or Mountain Meal, and is used in the form of powder for polishing stones and metals. It has been procured, among other places, from the mud of a lake at Dolgelly, in North Wales, and from Bilin, in Bohemia, in which latter place a single stratum, extending over a wide area, is no less than 14 feet thick. This stone, when examined with a powerful microscope, is found to consist of the siliceous tests of the Diatomaceæ figured below, united together without any visible cement. It is difficult to convey an idea of their extreme minuteness; but Ehrenberg estimates that in the Bilin tripoli there are 41,000 millions of individuals of the *Gallionella distans* (see fig. 16) in

Fig. 15.

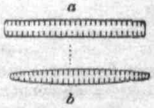


Gallionella ferruginea, Ehb.

Fig. 16.

Gallionella distans, Ehb.

Fig. 17.



Bacillaria paradoxa. *a.* Front view. *b.* Side view.

every cubic inch (which weighs about 220 grains), or about 187 millions in a single grain. At every stroke, therefore, that we make with this polishing powder, several millions, perhaps tens of millions, of perfect fossils are crushed to atoms.

A well-known substance, called bog-iron ore, often met with in peat-mosses, has been shown by Ehrenberg to consist of innumerable articulated threads, of a yellow ochre colour, composed of silica, argillaceous matter, and peroxide of iron. These threads are the cases of a minute microscopic body, called *Gallionella ferruginea* (fig. 15) associated with the siliceous plates of other freshwater algæ. Layers of this iron ore occurring in Scotch peat bogs are often called 'the pan,' and are sometimes of economical value.

It is clear that much time must have been required for the accumulation of strata to which countless generations of Diatomaceæ have contributed their remains; and these discoveries lead us naturally to suspect that other deposits, of which the materials have been supposed to be inorganic, may in reality be composed chiefly of microscopic organic bodies. That this is

the case with the white chalk, has often been imagined, and is now proved to be the fact. It has, moreover, been lately discovered that the chambers into which these Foraminifera are divided are actually often filled with thousands of well-preserved organic bodies, which abound in every minute grain of chalk, and are especially apparent in the white coating of flints, often accompanied by innumerable needle-shaped spiculæ of sponges. (see Chap. XVIII.)

The dust we tread upon was once alive!—BYRON.

How faint an idea does this exclamation of the poet convey of the real wonders of nature! for here we discover proofs that the calcareous and siliceous dust of which whole hills are composed has not only been once alive, but almost every particle, albeit invisible to the naked eye, still retains the organic structure which, at periods of time incalculably remote, was impressed upon it by the powers of life.

Freshwater and marine fossils.—Strata, whether deposited in salt or fresh water, have the same forms; but the embedded fossils are very different in the two cases, because the aquatic animals which frequent lakes and rivers are distinct from those inhabiting the sea. In the northern part of the Isle of Wight formations of marl and limestone, more than 50 feet thick, occur, in which the shells are of extinct species. Yet we recognise their freshwater origin, because they are of the same genera as those now abounding in ponds, lakes, and rivers, either in our own country or in warmer latitudes.

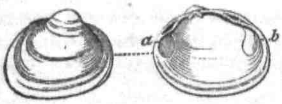
In many parts of France, in Auvergne, for example, strata occur of limestone, marl, and sandstone hundreds of feet thick, which contain exclusively freshwater and land shells, together with the remains of terrestrial quadrupeds. The number of land shells scattered through some of these freshwater deposits is exceedingly great; and there are districts in Germany where the rocks scarcely contain any other fossils except snail-shells (*helices*); as, for instance, the limestone on the left bank of the Rhine, between Mayence and Worms, at Oppenheim, Findheim, Budenheim, and other places. In order to account for this phenomenon, the geologist has only to examine the small deltas of torrents which enter the Swiss lakes when the waters are low, such as the newly formed plain where the Kander enters the Lake of Thun. He there sees sand and mud strewn over with innumerable dead land shells, which have been brought down from the valleys in the Alps in the preceding spring, during the melting of the snows. Again, if we search the sands on the borders of the Rhine, in the lower part of its course, we find

countless land shells mixed with others of species belonging to lakes, stagnant pools, and marshes. These individuals have been washed away from the alluvial plains of the great river and its tributaries, some from mountainous regions, others from the low country.

Although freshwater formations are often of great thickness, yet they are usually very limited in area when compared to marine deposits, just as lakes and estuaries are of small dimensions in comparison with seas.

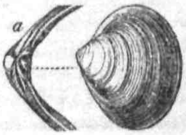
The absence of many fossil forms usually met with in marine strata, affords a useful negative indication of the freshwater

Fig. 18.



Cyclas (*Sphærium*) *corneus*, Sow.; living and fossil, nat. size.

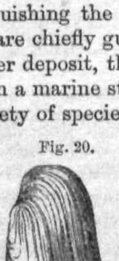
Fig. 19.



Cyrena (*Corbicella*) *fluminalis*, Möll.; fossil, Grays, Essex, and living in the Nile, nat. size.

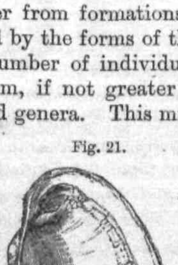
origin of a formation. For example, there are no sea-urchins, no corals, no chambered shells, such as the nautilus, nor microscopic Foraminifera in lacustrine or fluviatile deposits. In distinguishing the latter from formations accumulated in the sea, we are chiefly guided by the forms of the mollusca. In a freshwater deposit, the number of individual shells is often as great as in a marine stratum, if not greater; but there is a smaller variety of species and genera. This might be anticipated from

Fig. 20.



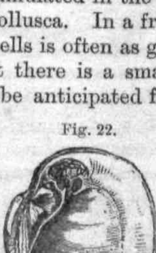
Anodonta Cordieri, D'Orb. Paris, ½.

Fig. 21.



Anodonta latimarginata; recent. Bahia.

Fig. 22.



Unio littoralis, Lam.; recent. Auvergne, ½.

the fact that the genera and species of recent freshwater and land shells are few when contrasted with the marine.

There are probably five times as many species of marine mollusca as those of terrestrial and freshwater kinds.

The majority of bivalve shells are marine, about one-ninth freshwater. Among these last, the four most common forms, both recent and fossil, are *Cyclas* (*Sphærium*), *Cyrena*, *Unio*, and *Anodonta* (see figures); the first two and last two of which are so nearly allied as to pass into each other.

Fig. 23.

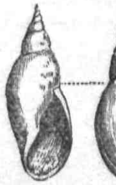
Gryphea incurva, Sow.: (*G. arcuata*, Lam.) upper valve. Lias, nat. size. Marine.

Lamarck divided the bivalve mollusca into the *Dimyary*, or those having two large muscular impressions in each valve, as *a b* in the Cyclas, fig. 18, and Unio, fig. 22, and the *Monomyary*, such as the oyster and scallop, in which there is only one of these impressions, as seen in fig. 23. Now, as none of these last, or the unimuscular bivalves, are freshwater,[2] we may at once presume a deposit containing any of them to be marine.

Fig. 24.

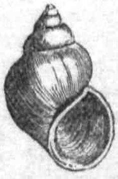
Planorbis euomphalus, Sow.; fossil. Isle of Wight, $\frac{2}{3}$.

Fig. 25.



Limnæa longiscata, Brong.; fossil. Isle of Wight, $\frac{1}{2}$.

Fig. 26.

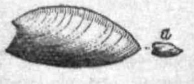


Paludina vivipara, Brand; living and fossil, nat. size.

Fig. 27.

Succinea amphibia, Drap. (S. Putris, L.); fossil. Loess, Rhine, nat. size.

Fig. 28.



Ancylus velletia (*A. elegans*), Sow.; fossil. Isle of Wight.

Fig. 29.

Valvata piscinalis, Müll.; fossil. Grays, Essex.

Fig. 30.

Physa hypnorum, Linn.; recent. Isle of Wight, nat. size.

[2] The freshwater Mulleria, which when young has two muscular impressions, has only one in the adult state, thus forming a single exception to the rule.

The univalve shells most characteristic of freshwater deposits are, *Planorbis*, *Limnæa*, and *Paludina*. But to these are occasionally added *Physa*, *Succinea*, *Ancylus*, *Valvata*, *Melanopsis*, *Melania*, *Potamides* and *Neritina* (see figures), the four last being usually found in estuaries.

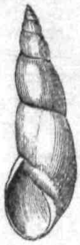
Fig. 31.

Auricula, recent. Ava, $\frac{1}{4}$.

Fig. 32.

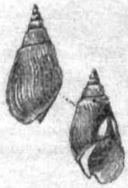
Cerithium funatum, Forbes. Isle of Wight.

Fig. 33.



Physa columnaris, Desh. Paris basin, $\frac{1}{2}$.

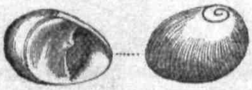
Fig. 34.



Melanopsis buccinoidea, Ferr.; recent. Asia, nat. size.

Some naturalists include *Neritina* (fig. 35) and the marine *Nerita* (fig. 36) in the same genus, it being scarcely possible to distinguish the two by good generic characters. But, as a general rule, the fluviatile species are smaller, smoother, and more globular than the marine; and they have never, like the *Neritæ*, the inner margin of the outer lip toothed or crenulated. (See fig. 36.)

Fig. 35.

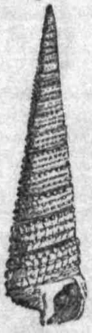


Neritina globulus, Def. Paris basin, nat. size.

Fig. 36.

Nerita granulosa, Desh. Paris basin, $\frac{1}{2}$.

Fig. 37.



Potamides cinctus, Sow. Paris basin, $\frac{2}{3}$.

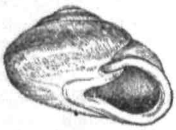
The Potamides inhabit the mouths of rivers in warm latitudes, and are distinguishable from the marine Cerithia by their orbicular and multispiral opercula. The genus Auricula (fig. 31) is amphibious, frequenting swamps and marshes within the influence of the tide.

The terrestrial shells are all univalves. The most important genera among these, both in a recent and fossil state, are *Helix* (fig. 38), *Cyclostoma* (fig. 39), *Pupa* (fig. 40), *Clausilia* (fig. 41), *Bulimus* (fig. 42), *Glandina*, and *Achatina*.

Ampullaria (fig. 43) is another genus of shells, inhabiting

rivers and ponds in hot countries. Many fossil species formerly referred to this genus, and which have been met with

Fig. 38.



Helix Turonensis, Desh.; Faluns, Touraine, nat. size.

Fig. 39.

Cyclostoma elegans, Müll.; Loess, nat. size.

Fig. 40.

Pupa tridens, Drap.; Loess, nat. size.

Fig. 41.

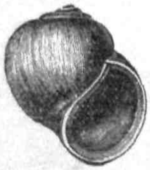
Clausilia bidens, Drap.; Loess, nat. size.

Fig. 42.

Bulimus lubricus, Müll.; Loess, Rhine.

chiefly in marine formations, are now considered by conchologists to belong to *Natica* and other marine genera.

Fig. 43.



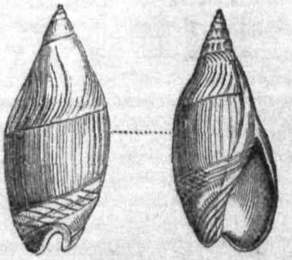
Ampullaria glauca, from the Jumna, ½.

All univalve shells of land and freshwater species, with the exception of *Melanopsis* (fig. 34), and *Achatina*, which has a slight indentation, have entire mouths: and this circumstance may often serve as a convenient rule for distinguishing freshwater from marine strata; since if any univalves occur of which the mouths are not entire, we may presume that the formation is marine. The aperture is said to be entire in such shells as the freshwater *Ampullaria* and the land shells (figs. 38–42), when its outline is not interrupted by an indentation or notch, such as that seen at *b*

Fig. 44.

Pleurotoma exorta, Brand. Upper and Middle Eocene, Barton and Bracklesham, nat. size.

Fig. 45.



Ancillaria subulata, Sow. Barton clay. Eocene, nat. size.

in *Ancillaria* (fig. 45); or is not prolonged into a canal, as that seen at *a* in *Pleurotoma* (fig. 44).

The mouths of a large proportion of the marine univalves

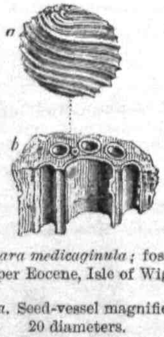
have these notches or canals, and almost all the species are carnivorous; whereas nearly all testacea having entire mouths are plant-eaters, whether the species be marine, freshwater, or terrestrial.

There is, however, one genus which affords an occasional exception to one of the above rules. The *Potamides* (fig. 37), a subgenus of Cerithium, although provided with a short canal, comprises some species which inhabit salt, others brackish, and others fresh water, and they are said to be all plant-eaters.

Among the fossils very common in freshwater deposits are the shells of *Cypris*, a minute bivalve crustaceous animal.[3] Many minute living species of this genus swarm in lakes and stagnant pools in Great Britain; but their shells are not, if considered separately, conclusive as to the freshwater origin of a deposit, because the majority of species in another kindred genus of the same order, the *Cytherina* of Lamarck, inhabit salt water; and, although the animal differs slightly, the shell is scarcely distinguishable from that of the *Cypris*.

Freshwater fossil plants.—The seed-vessels and stems of *Chara*, a genus of aquatic plants, are very frequent in freshwater strata. These seed-vessels were called, before their true

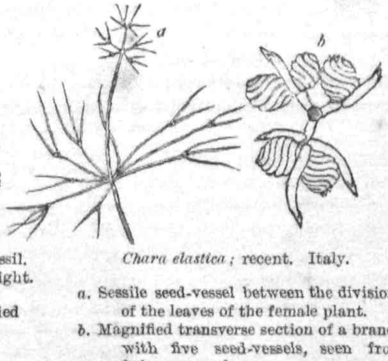
Fig. 46.



Chara medicaginula; fossil. Upper Eocene, Isle of Wight.

a. Seed-vessel magnified 20 diameters.
b. Stem, magnified.

Fig. 47.



Chara elastica; recent. Italy.

a. Sessile seed-vessel between the divisions of the leaves of the female plant.
b. Magnified transverse section of a branch with five seed-vessels, seen from below upwards.

nature was known, gyrogonites, and were supposed to be foraminiferous shells. (See fig. 46, *a*.)

The *Charæ* inhabit the bottom of lakes and ponds, and flourish mostly where the water is charged with carbonate of lime.

Their seed-vessels are covered with a very tough integument,

[3] For figures of fossil species of Purbeck, see Ch. XX.

capable of resisting decomposition: to which circumstance we may attribute their abundance in a fossil state. The annexed figure (fig. 47) represents a branch of one of many new species found by Professor Amici in the lakes of Northern Italy. The seed-vessel in this plant is more globular than in the British *Charæ*, and therefore more nearly resembles in form the extinct fossil species found in England, France, and other countries. The stems, as well as the seed-vessels, of these plants occur both in modern shell marl and in ancient freshwater formations. They are generally composed of a large central tube surrounded by smaller ones, the whole stem being divided at certain intervals by transverse partitions or joints. (See *b*, fig. 46.)

It is not uncommon to meet with layers of vegetable matter, impressions of leaves, and branches of trees, in strata containing freshwater shells; and we also find occasionally the teeth and bones of land quadrupeds, of species now unknown. The manner in which such remains are occasionally carried by rivers into lakes, especially during floods, has been fully treated of in the 'Principles of Geology.'

Freshwater and marine fish.—The remains of fish are occasionally useful in determining the freshwater origin of strata. Certain genera, such as carp, perch, pike, and loach (*Cyprinus*, *Perca*, *Esox*, and *Cobitis*), as also *Lebias*, being peculiar to fresh water. Other genera contain some freshwater and some marine species, as *Cottus*, *Mugil*, and *Anguilla*, or eel. The rest are either common to rivers and the sea, as the salmon; or are exclusively characteristic of salt water. The above observations respecting fossil fishes are applicable only to the more modern or tertiary deposits; for in the more ancient rocks the forms depart so widely from those of existing fishes, that it is very difficult, at least in the present state of science, to derive any positive information from ichthyolites respecting the element in which strata were deposited.

The alternation of marine and freshwater formations, both on a small and large scale, are facts well ascertained in geology. When it occurs on a small scale, it may have arisen from the alternate occupation of certain spaces by river water and the sea; for in the flood season the river forces back the ocean, and freshens it over a large area, depositing at the same time its sediment; after which the salt water again returns, and, on resuming its former place, brings with it sand, mud, and marine shells.

There are also lagoons at the mouths of many rivers, as the Nile and Mississippi, which are divided off by bars of sand from the sea, and which are filled with salt and fresh water by

turns. They often communicate exclusively with the river for months, years, or even centuries; and then, a breach being made in the bar of sand, they are for long periods filled with salt water.

Lym-Fjord.—The Lym-Fjord in Jutland offers an excellent illustration of analogous changes; for, in the course of the last thousand years, the western extremity of this long frith, which is 120 miles in length, including its windings, has been four times fresh and four times salt, a bar of sand between it and the ocean having been often formed and removed. The last irruption of salt water happened in 1824, when the North Sea entered, killing all the freshwater shells, fish, and plants; and from that time to the present, the seaweed *Fucus vesiculosus*, together with oysters and other marine mollusca, have succeeded the *Cyclas*, *Lymnea*, *Paludina*, and *Chara*.[4]

But changes like these in the Lym-Fjord, and those before mentioned as occurring at the mouths of great rivers, will only account for some cases of marine deposits of partial extent and thickness resting on freshwater strata. When we find, as in the south-east of England (Chap. XIX.), a great series of freshwater beds, 1,000 feet thick, resting upon marine formations and again covered by other rocks, such as the cretaceous, more than 1,000 feet thick, and of deep-sea origin, we shall find it necessary to seek for a different explanation of the phenomena.

Deep-sea deposits.—The surface of the sea is alive with minute organisms, many of which have skeletons or shells of carbonate of lime or of silica. These sink to the bottom after death. The floor of the deep sea is tenanted by living forms which have calcareous and siliceous tests, and the wreckage of the land and of coral islands is carried away and finally deposited on the ocean floor. Volcanic ash also falls in the sea and sinks, and pumice also.

The deposits accumulate very slowly on the ocean floor, and nothing is known about their thickness; they may be very thin, for fossils of old strata are often dredged up. In the northern seas, arenaceous deposits, with siliceous organisms, sponges, and foraminifera, and a few calcareous corals and foraminifera, are found. These deposits are somewhat analogous to ancient arenaceous marine deposits. As the depth increases, an oaze called Globigerina oaze is found, with from 35 to 65 per cent. of carbonate of lime in it, and a host of invertebrata with calcareous tests.

Then, with increasing depth is a grey oaze; and a red clay occupies vast tracts at profound depths. This clay contains much

[4] See Principles, Index, 'Lym-Fjord.'

manganese, silicate of alumina and lime, and is probably of volcanic origin. Towards the antarctic regions diatomaceous or siliceous deposits occur, and at different depths there are *Radiolaria*.

The Globigerina oaze resembles chalk to a certain extent, for it contains Coccospheres, Coccoliths, and Globigerina, but the percentage of carbonate of lime is much less than in the chalk.

CHAPTER IV.

CONSOLIDATION AND SUBSEQUENT ALTERATIONS OF STRATA AND PETRIFACTION OF FOSSILS.

Chemical and mechanical deposits—Cementing together of particles—Hardening by exposure to air—Concretionary nodules—Consolidating effects of pressure—Jointing—Mineralisation of organic remains—Impressions and casts, how formed—Fossil wood—Göppert's experiments—Precipitation of stony matter most rapid where putrefaction is going on—Sources of lime and silex in solution.

HAVING spoken in the preceding chapters of the characters of sedimentary formations, both as dependent on the deposition of inorganic matter and the distribution of fossils, I may next treat of the consolidation of stratified rocks, and the petrifaction of embedded organic remains.

Chemical and mechanical deposits.—A distinction has been made by geologists between deposits of a mechanical and those of a chemical origin. By the name mechanical are designated beds of mud, sand, or pebbles, produced by the action of running water, also accumulations of stones and scoriæ thrown out by a volcano, which have fallen into their present place by the force of gravitation. But the matter which forms a chemical deposit has not been mechanically suspended in water, but in a state of solution until separated by chemical action. In this manner carbonate of lime is occasionally precipitated upon the bottom of lakes in a solid form, as may be well seen in many parts of Italy, where mineral springs abound, and where the calcareous stone, called travertin, is deposited. In these springs the lime is usually held in solution by an excess of carbonic acid, or by heat if it be a hot spring, until the water, on issuing from the earth, cools or loses part of its acid. The calcareous matter then falls down in a solid state, encrusting shells, fragments of wood and leaves, and binding them together.

No similar travertin has been found in the bed of the sea,

for, as a general rule, the quantity of lime, according to Bischoff, spread through the waters of the ocean is very small: but it is found about coral reefs. Carbonate of lime is not precipitated at the bottom of the sea by chemical action alone, but must be produced by vital agency, as in the case of foraminiferal deposits. Caves often have stalactites suspended from their roof, and stalagmite forming layers on the floor, and these calcareous substances are in process of formation at the present time. Rain water percolating through soils takes up carbonic-acid gas, and this, in penetrating with the drainage through the limestone rock in which the cave is situated, displaces a certain amount of the carbonate of lime, and forms a bicarbonate which is soluble. The water thus charged drops from the roof, and gives off carbonic-acid gas, and a corresponding amount of carbonate of lime is set free in the form of pendants or stalactites. The excess of water which drops on to the floor in some instances precipitates its carbonate of lime in layers of stalagmite.

Now, the remarks already made in Chapter II. on the original horizontality of strata are strictly applicable to mechanical deposits, and only partially to those of a mixed nature. Such as are purely chemical may be formed on a very steep slope, or may even encrust the vertical walls of a fissure, and be of equal thickness throughout; but such deposits are of small extent, and for the most part confined to vein stones.

Consolidation of strata.—It is chiefly in the case of calcareous rocks that solidification takes place at the time of deposition. But there are many deposits in which a cementing process comes into operation long afterwards. We may sometimes observe, where the water of ferruginous or calcareous springs has flowed through a bed of sand or gravel, that iron or carbonate of lime has been deposited in the interstices between the grains or pebbles, so that in certain places the whole has been bound together into a stone, the same set of strata remaining in other parts loose and incoherent.

Proofs of a similar cementing action are seen in a rock at Kelloway in Wiltshire. A peculiar band of sandy strata belonging to the group called Oolite by geologists, may be traced through several counties, the sand being for the most part loose and unconsolidated, but becoming stony near Kelloway. In this district there are numerous fossil shells which have decomposed, having for the most part left only their casts. The calcareous matter hence derived has evidently served, at some former period, as a cement to the siliceous grains of sand, and thus a solid sandstone has been produced. If we take fragments of many other argillaceous grits, retaining the casts of shells, and

plunge them into dilute muriatic or other acid, we see them immediately changed into common sand and mud; the cement of lime, derived from the shells, having been dissolved by the acid.

Traces of impressions and casts are often extremely faint. In some loose sands of recent date we meet with shells in so advanced a stage of decomposition as to crumble into powder when touched. It is clear that water percolating such strata may soon remove the calcareous matter of the shell; and, unless circumstances cause the carbonate of lime to be again deposited, the grains of sand will not be cemented together; in which case no memorial of the fossil will remain.

It is evident that silica and carbonate of lime may become widely diffused in small quantities through the waters which permeate the earth's crust, and thus a stony cement is often supplied to sand, pebbles, or any fragmentary mixture. In some conglomerates, like the pudding-stone of Hertfordshire (a Lower Eocene deposit), pebbles of flint and grains of sand are united by a siliceous cement so firmly that, if a block be fractured, the rent passes as readily through the pebbles as through the cement.

It is probable that many strata became solid at the time when they emerged from the waters in which they were deposited, and when they first formed a part of the dry land. The consolidation was probably due to evaporation of the water, which penetrates the minutest pores of rocks, and the consequent deposition of carbonate of lime, iron, silica, and other minerals previously held in solution.

Most stones on being freshly quarried harden with exposure. Dr. MacCulloch mentions a sandstone in Skye which may be moulded like dough when first found; and some simple minerals, which are rigid and as hard as glass in our cabinets, are often flexible and soft in their native beds; this is the case with asbestos, sahlite, tremolite, and chalcedony, and it is reported also to happen in the case of the beryl.[1]

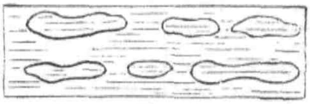
The marl recently deposited at the bottom of Lake Superior, in North America, is soft and often filled with freshwater shells; but if a piece be taken up and dried, it becomes so hard that it can only be broken by a smart blow of the hammer. If the lake, therefore, were drained, such a deposit would be found to consist of strata of marlstone, like that observed in many ancient European formations, and, like them, containing freshwater shells.

Concretionary structure.—It is probable that some of the heterogeneous materials which rivers transport to the sea may

[1] Dr. MacCulloch, Syst. of Geol. vol. i. p. 123.

at once set under water, like the artificial mixture called pozzolana, which consists of fine volcanic sand, charged with about 20 per cent. of oxide of iron, and the addition of a small quantity of lime. This substance hardens, and becomes a solid stone in water, and was used by the Romans in constructing the foundations of buildings in the sea. Consolidation, in such cases, is brought about by the chemical re-action which takes place between the different kinds of finely comminuted matter when previously suspended in water. After deposition similar particles seem often to exert a mutual attraction on each other, and congregate together in particular spots, forming lumps, nodules, and concretions. Thus, in many argillaceous deposits there are calcareous balls, or spherical concretions, ranged in layers parallel to the general stratification; an arrangement which took place after the shale or marl had been thrown down in successive laminæ; but these laminæ are often traceable through the concretions, remaining parallel to those of the surrounding unconsolidated rock. (See fig. 48.) Such nodules of limestone have often a shell or other foreign body in the centre.

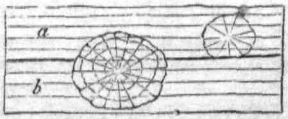
Fig. 48.



Calcareous nodules in Lias.

Among the most remarkable examples of concretionary structure are those described by Professor Sedgwick as abounding in the magnesian limestone of the north of England. The spherical balls are of various sizes, from that of a pea to a diameter of several feet, and they have both a concentric and radiated structure, while at the same time the laminæ of original deposition pass uninterruptedly through them. In some cliffs this limestone resembles a great irregular pile of cannon balls. Some of the globular masses have their centre in one stratum, while a portion of their exterior passes through to the stratum above or below. Thus the larger spheroid in the annexed section (fig. 49) passes from the stratum *b* upwards into *a*. In this instance we must suppose the deposition of a series of minor layers, first forming the stratum *b*, and afterwards the incumbent stratum *a*; then a movement of the particles took place, and the carbonates of lime and magnesia separated from the more impure and mixed matter forming the still unconsolidated parts of the stratum. Crystallisation, beginning

Fig. 49.



Spheroidal concretions in magnesian limestone.

at the centre, must have gone on forming concentric coats around the original nucleus without interfering with the laminated structure of the rock.

Effects of pressure.—When sand and mud sink to the bottom of a deep sea, the particles are not pressed down by the enormous weight of the incumbent ocean; for the water, which becomes mingled with the sand and mud, resists pressure with a force equal to that of the column of fluid above. The same happens in regard to organic remains which are filled with water under great pressure as they sink, otherwise they would be immediately crushed to pieces and flattened. Nevertheless, if the materials of a stratum remain in a yielding state, and do not set or solidify, they may be gradually squeezed down by the weight of other materials successively heaped upon them. By such downward pressure particles of clay, sand and marl become packed into a smaller space, and are made to cohere together permanently.

Analogous effects of condensation have arisen when the solid parts of the earth's crust have been forced in various directions by those mechanical movements hereafter to be described, by which strata have been bent, broken, and raised above the level of the sea. Rocks of more yielding materials must often have been forced against others previously consolidated, and may thus, by compression, have acquired a new structure.

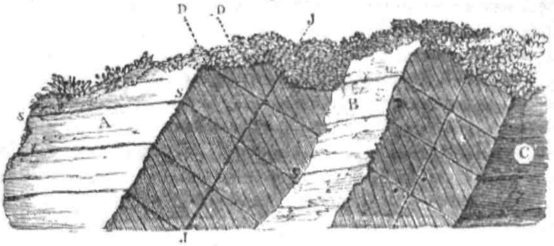
Jointed structure.—Joints are natural fissures which often traverse rocks in straight and well-determined lines, more or less at right angles to the line of bedding or stratification. If a sufficient number cross each other, the whole mass of rock is split into symmetrical blocks, and they afford to the quarryman the greatest aid in the extraction of blocks of stone. The faces of the joints are for the most part smoother and more regular than the surfaces of true strata. The joints are straight-cut chinks, sometimes slightly open, and often passing, not only through layers of successive deposition, but also through balls of limestone or other matter, which have been formed by concretionary action since the original accumulation of the strata, and in the case of conglomerates even through quartz pebbles. Such joints, therefore, must often have resulted from one of the last changes superinduced upon sedimentary deposits.

In the annexed diagram (fig. 50), the flat surfaces of rock A, B, C, represent exposed faces of joints, to which the walls of other joints, J J, are parallel. S S are the lines of stratification; D D are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.

In the Swiss and Savoy Alps, as Mr. Bakewell has remarked,

enormous masses of limestone are cut through so regularly by nearly vertical partings, and these joints are often so much more

Fig. 50.



Stratification, joints, and cleavage.
(From Murchison's 'Silurian System,' p. 245.)

conspicuous than the seams of stratification, that an inexperienced observer will almost inevitably confound them, and suppose the strata to be perpendicular in places where in fact they are almost horizontal.[2] Jukes observed joints in recently formed coral rock in the Australian and other reefs. Joints are due *to contraction of strata during consolidation*, and also *to* movements in the superficies of the crust.

Now such joints are supposed to be analogous to the partings which separate volcanic and plutonic rocks into cuboidal and prismatic masses. On a small scale we see clay and starch when dry split into similar shapes; this is often caused by simple contraction, whether the shrinking be due to the evaporation of water, or to a change of temperature. It is well known that many sandstones and other rocks expand by the application of moderate degrees of heat, and then contract again on cooling; and there can be no doubt that large portions of the earth's crust have, in the course of past ages, been subjected again and again to very different degrees of heat and cold. These alternations of temperature have probably contributed largely to the production of joints in rocks.

In many countries where masses of basalt rest on sandstone, the aqueous rock has for the distance of several feet from the point of junction assumed a columnar structure similar to that of the trap. In like manner some hearthstones, after exposure to the heat of a furnace without being melted, have become prismatic. Certain crystals also acquire a new internal arrangement by the application of heat, so as to break in a new direction, their external form remaining unaltered.

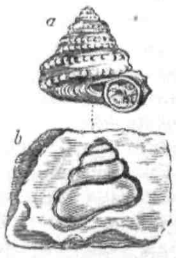
[2] *Introduction to Geology*, chap. iv.

Mineralisation of organic remains.—The changes which fossil organic bodies have undergone since they were first embedded in rocks throw much light on the consolidation of strata. Fossil shells in some modern deposits have been scarcely altered in the course of centuries, having simply lost a part of their animal matter. But in other cases the shell has disappeared, and left an impression only of its exterior, or secondly, a cast of its interior form, or thirdly, a cast of the shell itself, the original matter of which has been removed. These different forms of fossilization may easily be understood if we examine the mud recently thrown out from a pond or canal in which there are shells. If the mud be argillaceous, it acquires consistency on drying, and on breaking open a portion of it we find that each shell has left impressions of its external form. If we then remove the shell itself, we find within a solid nucleus of clay, having the form of the interior of the shell. This form is often very different from that of the outer shell. Thus a cast such as *a*, fig. 51, commonly called a fossil screw, would never be suspected by an inexperienced conchologist to be the internal shape of the fossil univalve, *b*, fig. 51. Nor should we have imagined at first sight that the shell *a* and the cast *b*, fig. 52,

Fig. 51.

Phasianella Heddingtonensis, and cast of the same. Coral Rag.

Fig. 52.



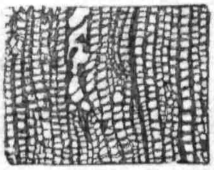
Pleurotomaria anglica, and cast. Lias, ⅓.

belong to one and the same fossil. The reader will observe in the last-mentioned figure (*b*, fig. 52), that an empty space shaded dark, which the *shell itself* once occupied, now intervenes between the enveloping stone and the cast of the smooth interior of the whorls. In such cases the shell has been dissolved and the component particles removed by water percolating the rock. If the nucleus were taken out, a hollow mould would remain, on which the external form of the shell with its tubercles and striæ, as seen in *a*, fig. 52, would be seen embossed. Now if the space alluded to between the nucleus and the impression,

instead of being left empty, has been filled up with calcareous spar, flint, pyrites, or other mineral, we then obtain from the mould an exact cast both of the external and internal form of the original shell. In this manner silicified casts of shells have been formed; and if the mud or sand of the nucleus happen to be incoherent, or soluble in acid, we can then procure in flint an empty shell, which in shape is the exact counterpart of the original. This cast may be compared to a bronze statue, representing merely the superficial form, and not the internal organisation; but there is another description of petrifaction by no means uncommon, and of a much more wonderful kind, which may be compared to certain anatomical models in wax, where not only the outward forms and features, but the nerves, blood-vessels, and other internal organs, are also shown. Thus we find corals, originally calcareous, in which not only the general shape, but also the minute and complicated internal organisation, is retained in flint.

Such a process of fossilization is still more remarkably exhibited in fossil wood, in which we often perceive not only the rings of annual growth, but all the minute vessels and medullary rays. Many of the minute cells and fibres of plants, and even those spiral vessels which in the living vegetable can only be discovered by the microscope, are preserved. Among many instances, I may mention a fossil tree, seventy-two feet in length, found at Gosforth, near Newcastle, in sandstone strata associated with coal. By cutting a transverse slice so thin as to transmit light, and magnifying it about fifty-five times, the texture as seen in fig. 53 is exhibited. A texture equally minute and complicated has been observed in the wood of large trunks of fossil trees found in the Craigleth quarry near Edinburgh, where the stone was not in the slightest degree siliceous, but consisted chiefly of carbonate of lime, with oxide of iron, alumina, and carbon. The parallel rows of vessels here seen are the rings of annual growth, but in one part they are imperfectly preserved, the wood having probably decayed before the mineralising matter had penetrated to that portion of the tree.

Fig. 53.



Transverse section of a tree from the coal measures, magnified, showing texture of wood.[3]

In attempting to explain the process of fossilization in such cases, we may first assume that strata are very generally permeated by water charged with minute portions of calcareous,

[3] Witham, Fossil Vegetables, 1831. Plate IV. fig. 1.

siliceous, and other earths in solution. In what manner they become so impregnated will be afterwards considered. If an organic substance is exposed in the open air to the action of the sun and rain, it will in time putrefy, or be dissolved into its component elements, consisting usually of oxygen, hydrogen, nitrogen and carbon. These will readily be absorbed by the atmosphere, or be washed away by rain, so that all vestiges of the dead animal or plant disappear. But if the same substances be submerged in water, they decompose more gradually; and if buried in earth, still more slowly; as in the familiar example of wooden piles or other buried timber. Now, if as fast as each particle is set free by putrefaction in a fluid or gaseous state, a particle equally minute of carbonate of lime, flint, or mineral, is at hand ready to be precipitated, we may imagine this inorganic matter to take the place just before left unoccupied by the organic molecule. In this manner a cast of the interior of certain vessels may first be taken, and afterwards the more solid walls of the same may decay and suffer a like transmutation. Yet when the whole is lapidified, it may not form one homogeneous mass of stone or metal. Some of the original ligneous, osseous, or other organic elements may remain mingled in certain parts, or the lapidifying substance itself may be differently coloured at different times, or so crystallised as to reflect light differently, and thus the texture of the original body may be faithfully exhibited.

The student may perhaps ask whether, on chemical principles, we have any ground to expect that mineral matter will be thrown down precisely in those spots where organic decomposition is in progress? The following curious experiments may serve to illustrate this point. Professor Göppert, of Breslau, with a view of imitating the natural process of fossilization, steeped a variety of animal and vegetable substances in waters, some holding siliceous, others calcareous, others metallic matter in solution. He found that in the period of a few weeks, or sometimes even days, the organic bodies thus immersed were mineralised to a certain extent. Thus, for example, thin vertical slices of deal, taken from the Scotch fir (*Pinus sylvestris*), were immersed in a moderately strong solution of sulphate of iron. When they had been thoroughly soaked in the liquid for several days they were dried and exposed to a red-heat until the vegetable matter was burnt up and nothing remained but an oxide of iron, which was found to have taken the form of the deal so exactly that casts even of the dotted vessels peculiar to this family of plants were distinctly visible under the microscope.

The late Dr. Turner observes, that when mineral matter is in a 'nascent state'—that is to say, just liberated from a previous state of chemical combination—it is most ready to unite with other matter, and form a new chemical compound. Probably the particles or atoms just set free are of extreme minuteness, and therefore move more freely, and are more ready to obey any impulse of chemical affinity. Whatever be the cause, it clearly follows, as before stated, that where organic matter newly embedded in sediment is decomposing, there will chemical changes take place most actively.

An analysis was lately made of the water which was flowing off from the rich mud deposited by the Hooghly river in the Delta of the Ganges after the annual inundation. This water was found to be highly charged with carbonic acid holding lime in solution.[4] Now if newly deposited mud is thus proved to be permeated by mineral matter in a state of solution, it is not difficult to perceive that decomposing organic bodies, naturally embedded in sediment, may as readily become petrified as the substances artificially immersed by Professor Göppert in various fluid mixtures.

The substance called kunker is a deposit of this carbonate of lime mixed with a little clay, in soils occasionally flooded, in India. The nodules of it collect around some little shell or other, but the flags of it are the result of slow deposition.

It is well known that the waters of all springs are more or less charged with earthy, alkaline, or metallic ingredients, derived from the rocks and mineral veins through which they percolate. Silica is especially abundant in hot springs, and carbonate of lime is almost always present in greater or less quantity. The materials for the fossilization of organic remains are, therefore, usually at hand in a state of chemical solution wherever organic remains are embedded in new strata.

[4] Piddington, Asiat. Research, vol. xviii. p. 226.

CHAPTER V.

ELEVATION OF STRATA ABOVE THE SEA—HORIZONTAL AND INCLINED STRATIFICATION.

Why the position of marine strata, above the level of the sea, should be referred to the rising up of the land, not to the going down of the sea—Strata of deep-sea and shallow-water origin alternate—Also marine and freshwater beds and old land surfaces—Vertical, inclined, and folded strata—Anticlinal and synclinal curves—Theories to explain lateral movements—Dip and strike—Structure of the Jura—Various forms of outcrop—Synclinal strata forming ridges—Connection of fracture and flexure of rocks—Inverted strata—Faults described—Superficial signs of the same obliterated by denudation—Great faults the result of repeated movements—Arrangement and direction of parallel folds of strata—Unconformability—Overlapping strata.

Land has been raised, not the sea lowered.—It has been already stated that the aqueous rocks containing marine fossils extend over wide continental tracts, and are seen in mountain chains rising to great heights above the level of the sea (p. 5). Hence it follows, that what is now dry land was once under water. But if we admit this conclusion, we must imagine, either that there has been a general lowering of the waters of the ocean, or that the solid rocks, once covered by water, have been raised up bodily out of the sea, and have thus become dry land. The earlier geologists, finding themselves reduced to this alternative, embraced the former opinion, assuming that the ocean was originally universal, and had gradually sunk down to its actual level, so that the present islands and continents were left dry. It seemed to them far easier to conceive that the water had gone down than that solid land had risen upwards into its present position. It was, however, impossible to invent any satisfactory hypothesis to explain the disappearance of so enormous a body of water throughout the globe, it being necessary to infer that the ocean had once stood at whatever height marine shells might be detected. It moreover appeared clear, as the science of Geology advanced, that certain spaces on the globe had been alternately sea, then land, then estuary, then sea again, and, lastly, once more habitable land, having remained in each of these states for considerable periods. In order to account for such phenomena, without admitting any movement of the land itself, we are required to imagine several retreats and returns of the ocean; and even then our theory applies merely to cases where the marine strata composing the dry

land are horizontal, leaving unexplained those more common instances where strata are inclined, curved, or placed on their edges, and evidently not in the position in which they were first deposited.

Geologists, therefore, were at last compelled to have recourse to the doctrine that the solid land has been repeatedly moved upwards or downwards, so as permanently to change its position relatively to the sea. There are several distinct grounds for preferring this conclusion. First, it will account equally for the position of those elevated masses of marine origin in which the stratification remains horizontal, and for those in which the strata are disturbed, broken, inclined, or vertical. Secondly, it is consistent with human experience that land should rise gradually in some places and be depressed in others. Such changes have actually occurred in our own days, and are now in progress, having been accompanied in some cases by violent convulsions, while in others they have proceeded so insensibly as to have been ascertainable only by the most careful scientific observations, made at considerable intervals of time. On the other hand, there is no evidence from human experience of a rising or lowering of the sea's level in any region, and the ocean cannot be raised or depressed in one place without its level being changed all over the globe.

*These preliminary remarks will prepare the reader to under*stand the great theoretical interest attached to all facts connected with the position of strata, whether horizontal or inclined, curved or vertical.

Now the first and most simple appearance is where strata of marine origin occur above the level of the sea in horizontal position. Such are the strata which we meet with in the south of Sicily, filled with shells for the most part of the same species as those now living in the Mediterranean. Some of these rocks rise to the height of more than 2,000 feet above the sea. Other mountain masses might be mentioned, composed of horizontal strata of high antiquity, which contain fossil remains of animals wholly dissimilar from any now known to exist. In the south of Sweden, for example, near Lake Wenér, the beds of some of the oldest fossiliferous deposits, called Silurian and Cambrian by geologists, occur in as level a position as if they had recently formed part of the delta of a great river, and been left dry on the retiring of the annual floods. Aqueous rocks, of equal antiquity extend for hundreds of miles over the lake-district of North America, and exhibit in like manner a stratification nearly undisturbed. The Table Mountain at the Cape of Good Hope is another example of highly elevated yet perfectly

horizontal strata, no less than 3,500 feet in thickness, and consisting of sandstone of very ancient date.

Instead of imagining that such fossiliferous rocks were always at their present level, and that the sea was once high enough to cover them, we suppose them to have constituted the ancient bed of the ocean, and to have been afterwards uplifted to their present height. This idea, however startling it may at first appear, is quite in accordance, as before stated, with the analogy of changes now going on in certain regions of the globe. Thus in parts of Sweden, and the shores and islands of the Gulf of Bothnia, proofs have been obtained that the land is experiencing, and has experienced for centuries, a slow upheaving movement.[1]

It appears, from the observations of Mr. Darwin and others, that very extensive regions of the continent of South America have been undergoing slow and gradual upheaval, by which the level plains of Patagonia, covered with recent marine shells, and the Pampas of Buenos Ayres, have been raised above the level of the sea. On the other hand, the gradual sinking of the west coast of Greenland, for the space of more than 600 miles from north to south, during the last four centuries, has been established by the observations of a Danish naturalist, Dr. Pingel. And while these proofs of continental elevation and subsidence, by slow and insensible movements, have been recently brought to light, the evidence has been daily strengthened of continued changes of level effected by violent convulsions in countries where earthquakes are frequent. There the rocks are rent from time to time, and heaved up or thrown down several feet at once, and disturbed in such a manner as to show how entirely the original position of strata may be modified in the course of centuries.

Mr. Darwin has also inferred that, in those parts of the Pacific and Indian Oceans where circular coral islands and barrier reefs abound, there is a slow and continued sinking of the submarine mountains on which the masses of coral are based, while there are other areas of the South Sea where the land is on the rise, and where coral has been upheaved far above the sea-level.

Along our coasts we find numerous submerged forests, only visible at low water, having the trunks of the trees erect and their roots attached to them and still spreading through the ancient soil as when they were living. They occur in too many places, and sometimes at too great a depth, to be explained by a mere change in the level of the tides, although, as the coasts

[1] See Principles of Geology, 1867, p. 314.

waste away and alter in shape, the height to which the tides rise and fall is always varying, and the level of high tide at any given point may, in the course of many ages, differ by several feet or even fathoms. It is this fluctuation in the height of the tides, and the erosion and destruction of the sea-coast by the waves, that makes it exceedingly difficult for us in a few centuries, or even perhaps in a few thousand years, to determine whether there is a change by subterranean movement in the relative level of sea and land.

We often behold, as on the coasts of Devonshire and Pembrokeshire, facts which appear to lead to opposite conclusions. In one place is a raised beach with marine littoral shells, and in another immediately adjoining may be a submerged forest.

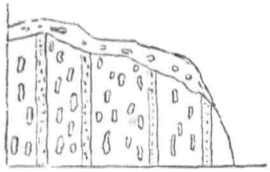
Alternations of marine and freshwater strata.—It has been shown in the third chapter that there is such a difference between land, freshwater, and marine fossils as to enable the geologist to determine whether particular groups of strata were formed at the bottom of the ocean or in estuaries, rivers, or lakes. If surprise was at first created by the discovery of marine corals and shells at the height of several miles above the sea-level, the imagination was afterwards not less startled by observing that in some successive strata composing the earth's crust, with a thickness amounting to thousands of feet, were comprised formations of shallow-sea as well as of deep-sea origin, of beds of brackish or even of purely freshwater formation, and of others containing vegetable matter or coal which accumulated on ancient land. In these cases we as frequently find freshwater beds below a marine set, or shallow water under those of deep-sea origin, as the reverse. Thus if we bore an Artesian well below London, we pass through a marine clay, and there reach, at the depth of several hundred feet, a shallow water and fluviatile sand, beneath which comes the white chalk originally formed in a deep sea. Or, if we bore vertically through the chalk of the North Downs, we come, after traversing marine chalky strata, upon a freshwater formation many hundreds of feet thick, called the Wealden, such as is seen in Kent and Surrey, which is known in its turn to rest on purely marine beds. In like manner, in various parts of Great Britain we sink vertical shafts through lacustrine deposits of great thickness, and come upon coal, which was formed by the growth of plants on an ancient land-surface.

Vertical, inclined, and curved strata.—It has been stated that marine strata of different ages are sometimes found at a considerable height above the sea, yet retaining their original horizontality; but this state of things is quite exceptional. As

a general rule, strata are inclined or bent in such a manner as to imply that their original position has been altered.

The most unequivocal evidence of such a change is afforded by their standing up vertically showing their edges, which is by no means a rare phenomenon, especially in mountainous countries. Thus we find in Scotland, on the southern skirts of the Grampians, beds of conglomerate alternating with thin layers of fine sand, all placed vertically to the horizon. When De Saussure first observed certain conglomerates in a similar position in the Swiss Alps, he remarked that the pebbles, being for the most part of an oval shape, had their longer axes parallel to the planes of stratification (see fig. 54). From this he inferred that such strata must, at first, have been horizontal, each oval pebble having settled at the bottom of the water, with its flatter side parallel to the horizon. Some few, indeed, of the rounded stones in a conglomerate occasionally afford an exception to the above rule, for the same reason that in a river's bed, or in a shingle beach, some pebbles rest on their ends or edges ; these having been shoved against or between other stones by a wave or current so as to assume this position.

Fig. 54.



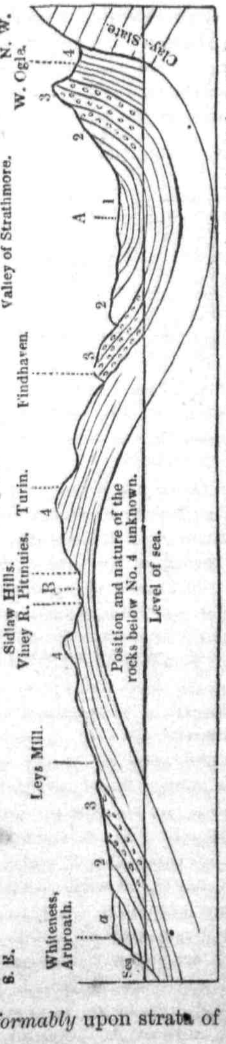
Vertical conglomerate and sandstone.

Anticlinal and synclinal curves.—Vertical strata, when they can be traced continuously upwards or downwards for some depth, are almost invariably seen to be parts of great curves, which may have a diameter of a few yards or of several miles. I shall first describe two curves of considerable regularity, which occur in Forfarshire, extending over a country twenty miles in breadth, from the foot of the Grampians to the sea near Arbroath.

The mass of strata exhibited may be 2,000 feet in thickness, consisting of red and white sandstone and various coloured shales, the beds being distinguishable into four principal groups —namely : No. 1, red marl or shale ; No. 2, red sandstone, used for building ; No. 3, conglomerate ; and No. 4, grey paving-stone, and tile-stone with green and reddish shale, containing peculiar organic remains. A glance at the section will show that each of the formations 2, 3, 4 is repeated thrice at the surface, twice with a southerly, and once with a northerly inclination or *dip* ; and the beds in No. 1, which are nearly horizontal, are still brought up twice by a slight curvature to the surface, once on each side of A. Beginning at the north-west extremity, the

tile-stones and conglomerates, No. 4 and No. 3, are vertical, and they generally form a ridge parallel to the southern skirts of the Grampians. The superior strata, Nos. 2 and 1, become less and less inclined on descending to the valley of Strathmore, where the strata, having a concave bend, are said by geologists to lie in a 'trough' or 'basin.' Through the centre of this valley runs an imaginary line A, called technically a 'synclinal axis,' where the beds, which are tilted in opposite directions, may be supposed to meet. It is most important for the observer to mark such axes, for he will perceive by the diagram that, in travelling from the north to the centre of the basin, he is always passing from older to newer beds; whereas, after crossing the line A, and pursuing his course in the same southerly direction, he is continually leaving the newer, and advancing upon older strata. All the deposits which he had before examined begin then to recur in reversed order, until he arrives at the central axis of the Sidlaw hills, where the strata are seen to form an arch or *saddle*, having an *anticlinal* axis B in the centre. On passing this axis, and continuing towards the S.E., the formations 4, 3, and 2 are again repeated, in the same relative order of superposition, but with a southerly dip. At Whiteness (see diagram) it will be seen that the inclined strata are covered by a newer deposit, *a*, in horizontal beds. These are composed of red conglomerate and sand, and are newer than any of the groups, 1, 2, 3, 4, before described, and rest *unconformably* upon strata of the sandstone group No. 2.

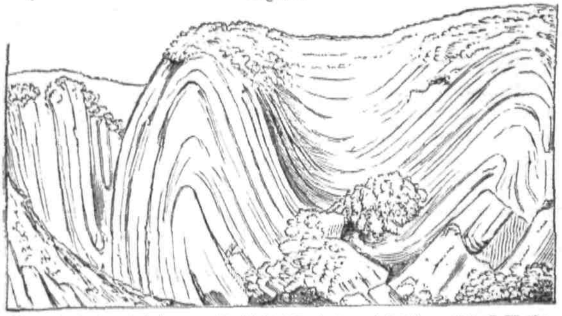
Fig. 55.



Section of Forfarshire, from N. W. to S. E., from foot of the Grampians to the sea at Arbroath (volcanic or trap rocks omitted).
Length of section twenty miles.

An example of curved strata, in which the bends or plications of the rock are sharper and far more numerous within an equal space, has been well described by Sir James Hall.[2] It occurs near St. Abb's Head, on the east coast of Scotland, where the rocks consist principally of a bluish slate, having frequently a ripple-marked surface. The undulations of the beds reach from the top to the bottom of cliffs from 200 to 300 feet in height,

Fig. 56.



Curved strata of slate near St. Abb's Head, Berwickshire. (Sir J. Hall.)

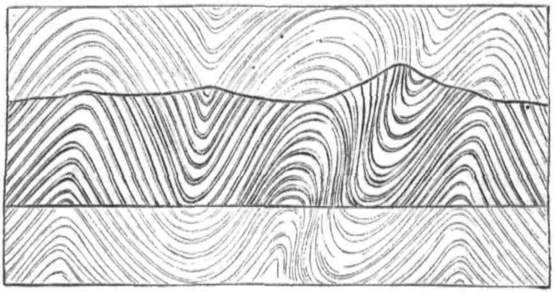
and there are sixteen distinct bendings in the course of about six miles, the curvatures being alternately concave and convex upwards. All these strata were once horizontal.

Folding by lateral movement.—An experiment was made by Sir James Hall, with a view of illustrating the manner in which such strata, assuming them to have been originally horizontal, may have been forced into their present position. A set of layers of clay were passed under a weight, and their opposite ends pressed towards each other with such force as to cause them to approach more nearly together. On the removal of the weight the layers of clay were found to be curved and folded, so as to bear a miniature resemblance to the strata in the cliffs. We must, however, bear in mind that in the natural section or sea-cliff we only see the foldings imperfectly, one part being invisible beneath the sea, and the other, or upper portion, being supposed to have been carried away by *denudation*, or that action of water which will be explained in the next chapter. The dark lines in the accompanying plan (fig. 57) represent what is actually seen of the strata in the line of cliff alluded to; the fainter lines indicate that portion which is concealed beneath the sea-level, as also that which is supposed to have once existed above the present level.

[2] Edin. Trans. vol. vii. pl. 3.

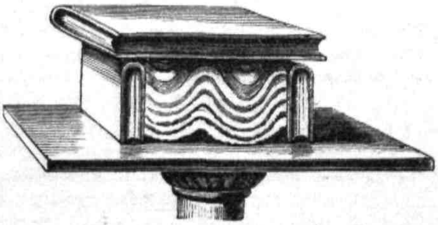
We may still more easily illustrate the effects which a lateral thrust must produce on flexible strata, by placing several

Fig. 57.



pieces of differently coloured cloths upon a table, and when they are spread out horizontally, cover them with a book. Then apply other books to each end, and force them towards each other. The folding of the cloths (see fig. 58) will imitate those of the bent strata; the incumbent book being slightly

Fig. 58.

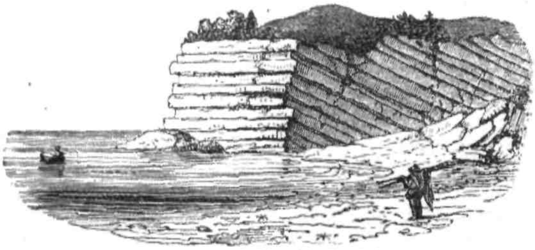


lifted up, and no longer touching the two volumes on which it rested before, because it is supported by the tops of the anticlinal ridges formed by the curved cloths. In like manner there can be no doubt that the squeezed strata, although laterally condensed and more closely packed, are yet elongated and made to rise upwards in a direction perpendicular to the pressure.

Whether the analogous flexures in stratified rocks have really been due to similar sideway movements is a question which we cannot decide by reference to our own observation. Our inability to explain the nature of the process is, perhaps, not simply owing to the inaccessibility of the subterranean regions where the mechanical force is exerted, but to the extreme

section exactly at right angles to the line of the strike, we are then able to ascertain the true dip. In the annexed drawing (fig. 60), we may suppose a headland, one side of which faces to

Fig. 60.

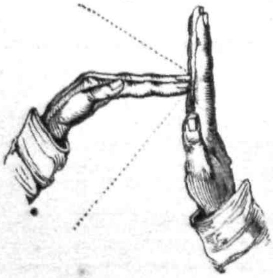


Apparent horizontality of inclined strata.

the north, where the beds would appear perfectly horizontal to a person in the boat; while on the other side, facing the west, the true dip would be seen by the person on shore to be at an angle of 40°. If, therefore, our observations are confined to a vertical precipice facing in one direction, we must endeavour to find a ledge or portion of the plane of one of the beds projecting beyond the others, in order to ascertain the true dip.

If not provided with a clinometer, a most useful instrument when it is of consequence to determine the inclination of the strata with precision, the observer may measure the angle within a few degrees, by standing exactly opposite to a cliff where the true dip is exhibited, holding the hands immediately before the eyes, and placing the fingers of one in a perpendicular and of the other in a horizontal position, as in fig. 61. It is thus easy to discover whether the lines of the inclined beds bisect the angle of 90°, formed by the meeting of the hands, so as to give an angle of 45°, or whether it would divide the space into two equal or unequal portions. You have only to change hands to get the dip indicated by the lower dotted line on the upper side of the horizontal hand.

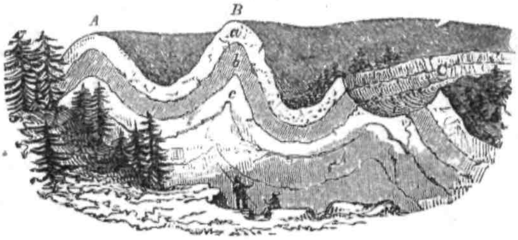
Fig. 61.



It has been already seen, p. 51, in describing the curved strata on the east coast of Scotland, in Forfarshire and Berwick-

shire, that a series of concave and convex bendings are occasionally repeated several times. These usually form part of a series of parallel waves of strata, which are prolonged in the same direction, throughout a considerable extent of country. Thus, for example, in the Swiss Jura, that lofty chain of mountains has been proved to consist of many parallel ridges, with intervening longitudinal valleys, as in fig. 62, the ridges being formed by curved fossiliferous strata, the nature and dip of

Fig. 62.

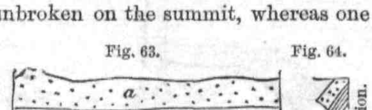


Section illustrating the structure of the Swiss Jura.

which are occasionally displayed in deep transverse gorges, called 'cluses,' caused by fractures at right angles to the direction of the chain.[3] Now let us suppose these ridges and parallel valleys to run north and south, we should then say that the *strike* of the beds is north and south, and the *dip* east and west. Lines drawn along the summits of the ridges A, B, would be anticlinal axes, and one following the bottom of the adjoining valleys a synclinal axis.

Outcrop of strata.—It will be observed that some of these ridges, A, B (fig 62), are unbroken on the summit, whereas one of them, C, has been fractured along the line of strike, and a portion of it carried away by denudation, so that the ridges of the beds in the formations *a*, *b*, *c*, come out to the day, or, as the miners say, *crop out*, on the sides of a valley.

Fig. 63. Fig. 64.



Ground plan of the denuded ridge C, fig. 62.

The ground plan of such a denuded ridge as C, as given in a geological map, may be expressed by the diagram fig. 63, and the cross section of the same by fig. 64. The line D E, fig. 63,

[3] Thurmann, 'Essai sur les Soulèvemens Jurassiques du Porrentruy,' Paris, 1832.

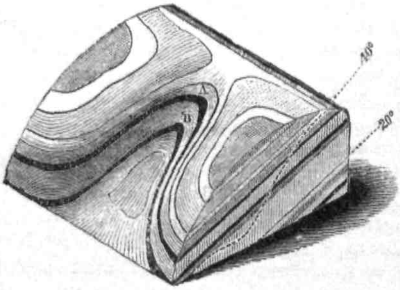
is the anticlinal line, on each side of which the dip is in opposite directions, as expressed by the arrows. The emergence of strata at the surface is called by miners their *outcrop* or *basset*.

If, instead of being folded into parallel ridges, the beds form a boss or dome-shaped protuberance, and if we suppose the summit of the dome carried off, the ground plan would exhibit the edges of the strata forming a succession of circles, or ellipses, round a common centre. These circles are the lines of strike, and the dip being always at right angles is inclined in the course of the circuit to every point of the compass, constituting what is termed a quâ-quâversal dip—that is, turning every way.

There are endless variations in the figures described by the basset-edges of the strata, according to the different inclination of the beds, and the mode in which they happen to have been denuded. One of the simplest rules, with which every geologist should be acquainted, relates to the V-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal, the V-like form will be also on a level, and the newest strata will appear at the greatest heights.

Secondly, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the beds be less steep than the slope of the valley, then the V's, as they are

Fig. 65.



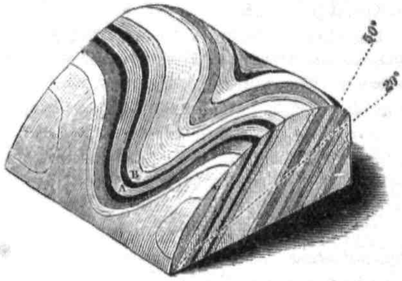
Slope of valley 40°, dip of strata 20°.

often termed by the miners, will point upwards (see fig. 65), those formed by the newer beds appearing in a superior position, and extending highest up the valley, as A is seen above B.

Thirdly, if the dip of the beds be steeper than the slope of the valley, then the V's will point downwards (see fig. 66), and those formed of the older beds will now appear uppermost, as B appears above A.

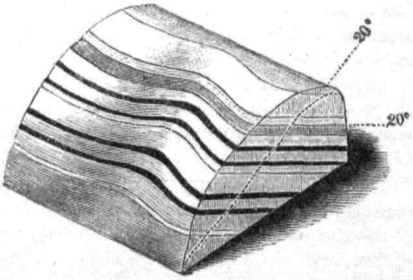
Fourthly, in every case where the strata dip in a contrary direction to the slope of the valley, whatever be the angle of inclination, the newer beds will appear the highest, as in the first and second cases. This is shown by the drawing (fig. 67), which exhibits strata rising at an angle of 20°, and crossed by a valley, which declines in an opposite direction at 20°.

Fig. 66.



Slope of valley 20°, dip of strata 50°.

Fig. 67.



Slope of valley 20°, dip of strata 20°, in opposite directions.

These rules may often be of great practical utility; for the different degrees of dip occurring in the two cases represented in figs. 65 and 66 may occasionally be encountered in following the same line of flexure at points a few miles distant from each other. A miner unacquainted with the rule, who had first explored the valley (fig. 65), may have sunk a vertical shaft below the coal seam A, until he reached the inferior bed B. He might then pass to the valley (fig. 66), and discovering there also the outcrop of two coal seams, might begin his workings in the uppermost in the expectation of coming down to the other bed A, which would be observed cropping out lower down the valley. But a glance at the section will demonstrate the futility of such hopes.[4]

Synclinal strata forming ridges.—Although in many cases an anticlinal axis forms a ridge, and a synclinal axis a valley, as

[4] Sir C. Lyell was indebted to the kindness of the late T. Sopwith, Esq., for three models which he had copied in the above diagrams; but the beginner may find it by no means easy to understand such copies, although, if he were to examine and handle the originals, turning them

in A B, fig. 62, p. 57, yet this can by no means be laid down as a general rule, as the beds very often slope inwards from either side of a mountain, as at *a*, *b*, fig. 68, while in the intervening valley *c* they slope upwards, forming an arch.

It would be natural to expect the fracture of solid rocks to take place chiefly where the bending of the strata has been sharpest, and such rending may produce ravines, giving access to running water and exposing the surface to atmospheric waste.

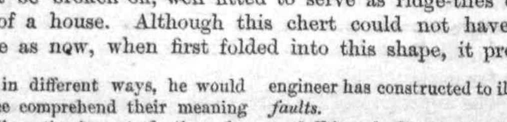
Fig. 68.

Section of carboniferous rocks of Lancashire. (E. Hull.)[5]

The entire absence, however, of such cracks at points where the strain must have been greatest, as at *a*, fig. 62, is often very remarkable and not always easy of explanation. We must imagine that many strata of limestone, chert, and other rocks which are now brittle, were pliant when bent into their present position. They have owed their flexibility in part to the fluid matter which they contain in their minute pores, as before described (p. 38), and in part to the permeation of sea-water, while they were yet submerged.

At the western extremity of the Pyrenees, great curvatures of the strata are seen in the sea-cliffs, where the rocks consist of

Fig. 69.



Strata of chert, grit, and marl near St. Jean de Luz.

marl, grit, and chert. At certain points, as at *a*, fig. 69, some of the bendings of the flinty chert are so sharp, that specimens might be broken off, well fitted to serve as ridge-tiles on the roof of a house. Although this chert could not have been brittle as now, when first folded into this shape, it presents,

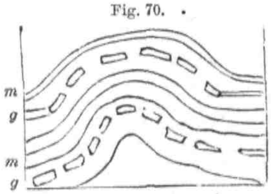
about in different ways, he would at once comprehend their meaning as well as the import of others far more complicated, which the same engineer has constructed to illustrate *faults*.

[5] Edward Hull, Quart. Geol. Journ. vol. xxiv. p. 324. 1868.

nevertheless, here and there at the points of greatest flexure small cracks, which show that it was solid, and not wholly incapable of breaking, at the period of its displacement. The numerous rents alluded to are not empty, but filled with chalcedony and quartz.

Between San Caterina and Castrogiovanni, in Sicily, bent and undulating gypseous marls occur, with here and there thin beds of solid gypsum interstratified. Sometimes these solid layers have been broken into detached fragments, still preserving their sharp edges (*g g*, fig. 70), while the continuity of the more pliable and ductile marls, *m m*, has not been interrupted.

Fig. 70.



g gypsum. *m* marl.

We have already explained (fig. 68) that stratified rocks have their strata usually bent into parallel folds forming anticlinal and synclinal curves, a group of several of these folds having often been subjected to a common movement, and having acquired a uniform strike or direction. In some disturbed regions these folds have been doubled back upon themselves in such a manner that it is often difficult for an experienced geologist to determine the relative age of the beds correctly by superposition. Thus, if we meet with the strata seen in the section, fig. 71, we should naturally suppose that there were twelve distinct beds, or sets of beds, No. 1, the uppermost, being the newest, and No. 12 the oldest of the series. But this section may perhaps exhibit merely six beds, which have been folded in the manner seen in fig. 72, so that each of them is twice repeated, the position of one-half being reversed, and part of No. 1, originally the uppermost, having now become the lowest of the series. The upper part of the curves seen in this diagram, fig. 72, and expressed in fainter lines, has been removed by denudation.

Fig. 71.

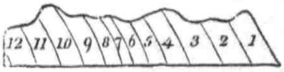
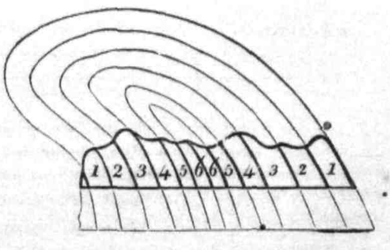


Fig. 72.

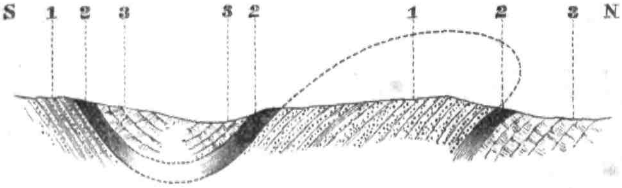


The phenomena of folding, inversion and reversal of strata

are seen on a magnificent scale in certain regions in Switzerland, in precipices often more than 2,000 feet in perpendicular height, and there are flexures not inferior in dimensions in the Pyrenees.

Strata are seen not unfrequently, on the flanks of great mountain chains, in such sharp and inclined folds that the denudation which has worn away parts of them leaves the beds presenting all the appearances of being reversed, that is to say, the oldest strata are on the top of the newer.

Fig. 73.



Inverted beds near Milford Haven. (After Green.)

3. Top. Carboniferous limestone.
2. Lower limestone shale.
1. Bottom. Old red sandstone.

Ordinary inversion of strata is well seen near Milford, and is explained in the above diagram. On passing from N to S the topmost strata, 3, are lower than 2 and 1.

The folding is on such a grand scale and has been so sharp in the Alps that old metamorphic rocks, whose place is below the sedimentary strata, have become included in the folds and exposed by denudation. The old rocks then appear newer than some of the younger strata. In the Mont Blanc range the lateral crush has been sufficient to cause the sedimentary strata to dip under the old crystalline schists, as will be explained when treating of metamorphic rocks.

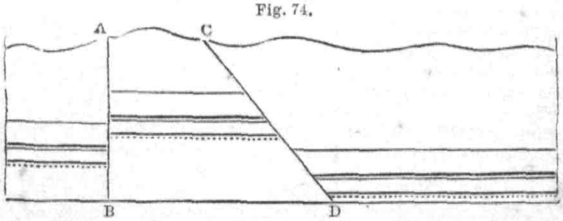
Fractures of the strata and faults.—Numerous rents may often be seen in rocks which appear to have been simply broken, the fractured parts still remaining in contact; but we often find a fissure, several inches or yards wide, intervening between the disunited portions. These fissures are usually filled with fine earth and sand, or with angular fragments of stone, evidently derived from the fracture of the contiguous rocks.

The face of each wall of the fissure is often beautifully polished, as if glazed, striated, or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These polished surfaces are called by miners 'slickensides.' It is supposed that the lines of the striæ indicate the direction in which the rocks

were moved. During one of the minor earthquakes in Chili, in *1840*, the brick *walls* of a *building* were rent *vertically* in several places, and made to vibrate for several minutes during each *shock*, *after* which they *remained uninjured*, *and without any* opening, although the line of each crack was still visible. When all movement had ceased, there were seen on the floor of the house, at the bottom of each rent, small heaps of fine brick-dust, evidently produced by trituration.

It is not uncommon to find the mass of rock, on one side of a fissure, thrown up above or down below the mass with which it was once in contact on the other side. 'This mode of displacement is called a fault, shift, slip, or throw.' Playfair, in *describing a fault*, remarks: '*The miner is often perplexed, in* his subterraneous journey, by a derangement in the strata, which changes at once all those lines and bearings which had hitherto directed his course. When his mine reaches a certain plane, which is sometimes perpendicular, as in A B, fig. 74, sometimes oblique to the horizon (as in C D, ibid.), he finds the beds of rock broken asunder, those on the one side of the plane having changed their place, by sliding in a particular direction along the face of the others. In this motion they have sometimes

Fig. 74.



Faults. A B perpendicular, C D oblique to the horizon.

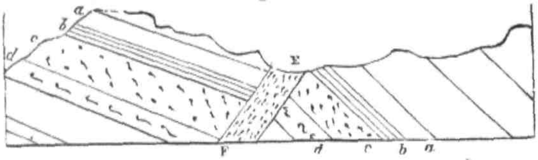
preserved their parallelism, as in fig. 74, so that the strata on each side of the faults A B, C D, continue parallel to one another; in other cases, the strata on each side are inclined, as in *a*, *b*, *c*, *d* (fig. 75), though their identity is still to be recognised by their possessing the same thickness and the same internal characters.[6]

Faults are sometimes vertical, as at A B, fig. 74, but usually they are inclined (C D). The inclination of a fault from the vertical is called its hade. Lateral displacement of strata occurs in relation to the departure of the fault from the vertical. Usually, the ends of strata close to a fault are more or less bent: those which have dropped down are bent up against the

[6] Playfair, Illust. of Hutt. Theory, § 42.

line of fault, and those which have been pushed up have their edges forced downwards.

Fig. 75.



E F fault or fissure filled with rubbish, on each side of which the shifted strata are not parallel.

In Coalbrook Dale[7] deposits of sandstone, shale, and coal, several thousand feet thick and occupying an area of many miles, have been shivered into fragments, and the broken remnants have been placed in very discordant positions, often at levels differing several hundred feet from each other. The sides of the faults, when perpendicular, are commonly several yards apart, and are sometimes as much as 50 yards asunder, the interval being filled with broken *débris* of the strata. In following the course of the same fault it is sometimes found to produce in different places very unequal changes of level, the amount of shift being in one place 300 and in another 700 feet, which arises from the union of two or more faults. In other words, the disjointed strata have in certain districts been subjected to renewed movements, which they have not suffered elsewhere.

We may occasionally see exact counterparts of these slips, on a small scale, in pits of loose sand and gravel, many of which have doubtless been caused by the drying and shrinking of argillaceous and other beds, slight subsidences having taken place from failure of support. Sometimes, however, even these small slips may have been produced during earthquakes ; for land has been moved, and its level, relatively to the sea, considerably altered, since much of the alluvial sand and gravel now covering the surface of continents was deposited.

A remarkable instance of the occurrence of the changes just alluded to, in modern times, was observed in New Zealand during the earthquake of January, 1855.[8] In the course of the subterranean disturbances a fracture in the strata was produced, extending for a distance of 90 miles. On one side of this fissure, the land was elevated in places as much as 9 feet, so as to form an inland cliff of that height, but on the other side the strata were unaffected. At the same time, a large district in the

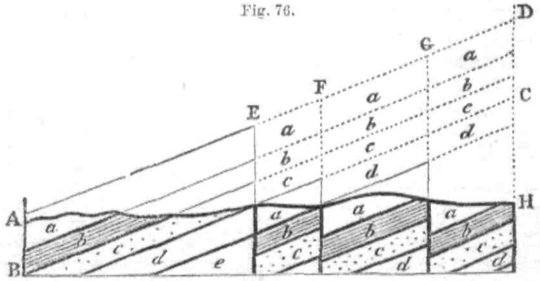
[7] Prestwich, Geol. Trans. second series, vol. v. p. 452.
[8] Principles, 10th ed. vol. ii. p. 83.

North Island, in the neighbourhood of Wellington, was upraised, while on the opposite side of Cook's Strait a subsidence of 5 feet took place, so that ships were obliged to go three miles higher up the river Wairau to obtain a supply of fresh water.

I have already stated that a geologist must be on his guard, *in a region of disturbed strata, against inferring* repeated alternations of rocks, when, in fact, the same strata, once continuous, have been bent round so as to recur in the same section, and with the same dip. A similar mistake has often been occasioned by a series of faults.

If, for example, the dark line A H (fig. 76) represents the surface of a country on which the strata *a b c* frequently crop

Fig. 76.



Apparent alternations of strata caused by vertical faults.

out, an observer, who is proceeding from H to A, might at first imagine that at every step he was approaching new strata, whereas the repetition of the same beds has been caused by vertical faults, or downthrows. Thus, suppose the original mass, A, B, C, D, to have been a set of uniformly inclined strata, and that the different masses under E F, F G, and G D, sank down successively, so as to leave vacant the spaces marked in the diagram by dotted lines, and to occupy those marked by the continuous lines, then let denudation take place along the line A H, so that the protruding masses indicated by the fainter lines are swept away—a miner who has not discovered the faults, finding the mass *a*, which we will suppose to be a bed of coal four times repeated, might hope to find four beds, workable to an indefinite depth, but first on arriving at the fault G he is stopped suddenly in his workings, for he comes partly upon the shale *b*, and partly on the sandstone *c*; the same result awaits him at the fault F, and on reaching E he is again stopped by a wall composed of the rock *d*.

The very different levels at which the separated parts of the same strata are found on the different sides of the fissure, in some faults, are truly astonishing. One of the most celebrated faults in England is called the 'ninety-fathom dike,' in the coal-field of Newcastle. This name has been given to it because the same beds are ninety fathoms (540 feet) lower on the northern than they are on the southern side. The fissure has been filled by a body of sand, which is now in a state of sandstone, and is called the dike, which is sometimes very narrow, but in other places more than twenty yards wide.[9] The walls of the fissure are scored by grooves, such as would have been produced if the broken ends of the rock had been rubbed along the plane of the fault.[1] In the Tynedale and Craven faults, in the north of England, the vertical displacement, or 'amount of throw,' as it is technically called, is still greater, and the fracture has extended in a horizontal direction for a distance of thirty miles or more. Some faults run in the same direction as the dip of the strata; they produce a lateral shift of the beds. Others are along the strike, and often blot out strata by not allowing them to reach the surface. Step faults carry down a stratum, which may be near the surface, by a series of parallel dislocations, so that it becomes deeper and deeper, as it were, along a set of steps.

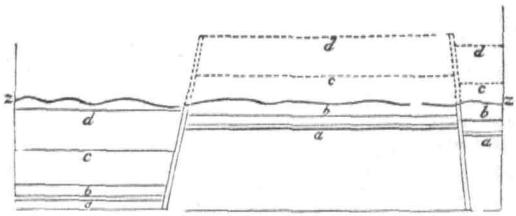
Great faults the result of repeated movements.—It must not, however, be supposed that faults generally consist of single linear rents; there are usually a number of faults springing off from the main one, and sometimes a long strip of country seems broken up into fragments by sets of parallel and connecting transverse faults. Oftentimes a great line of fault has been repeated or the movements have been continued through successive periods, so that newer deposits having covered the old line of displacement, the strata both newer and older have given way along the old line of fracture. Some geologists have considered it necessary to imagine that the upward or downward movement in these cases was accomplished at a single stroke, and not by a series of sudden but interrupted movements. They appear to have derived this idea from a notion that the grooved walls have merely been rubbed in one direction, which is far from being a constant phenomenon. Not only are some sets of striæ not parallel to others, but the clay and rubbish between the walls, when being squeezed or rubbed, have been streaked in different directions, the grooves which the harder minerals have impressed on the softer being frequently curved and irregular.

[9] Conybeare and Phillips, Outlines, &c. p. 376.

[1] Phillips, Geology, Lardner's Cyclop. p. 41.

Protruding masses of rock forming precipices or ridges along the lines of great faults may occur; but they have usually been removed by denudation. This is well exemplified in nearly every coal-field which has been extensively worked. It is in such districts that the former relation of the beds which have been shifted is determinable with great accuracy. Thus in the coal-field of Ashby-de-la-Zouch, in Leicestershire (see fig. 77),

Fig. 77.



Faults and denuded coal strata, Ashby-de-la-Zouch. (Mammatt.)

a fault occurs, on one side of which the coal-beds, *a b c d*, must once have risen to the height of 500 feet above the corresponding beds on the other side. But the uplifted strata do not stand up 500 feet above the general surface; on the contrary, the outline of the country, as expressed by the line *z z*, is uniformly undulating without any break, and the mass indicated by the dotted outline must have been denuded off and carried away.

In the Lancashire coal-field the vertical displacement has amounted to thousands of feet, and yet all the superficial inequalities which must have resulted from such movements have been obliterated by subsequent denudation. It appears that there are proofs of there having been two periods of vertical movement in one of the faults—one, for example, before, and another after the Triassic epoch.

An hypothesis which attributes such a change of position to a succession of movements is far preferable to any theory which assumes each fault to have been accomplished by a single up-cast or downthrow of several thousand feet. For we know that there are operations now in progress, at great depths in the interior of the earth, by which both large and small tracts of ground are made to rise above and sink below their former level, some slowly and insensibly, others suddenly and by starts, a few feet or yards at a time; whereas there are no grounds for believing that, during the last 3,000 years at least, any regions have been either upheaved or depressed, at a single stroke,

to the amount of several hundred, much less several thousand, feet.

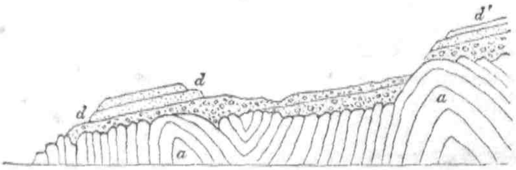
Faulting on a very grand scale accompanied mountain formation, and appears to have occurred at the close of the action of the tangential thrust, or the from side to side force, which curved and upheaved the mass.

As a rule, mountains of different ages have the direction of their folds of strata along different lines of strike. The force producing the curves was directed at right angles to the line of strike.

After the cessation of the crushing action, dislocations occurred along the flanks of the mountain ranges, that is to say, along the lines of strike of the component strata, and strike faults were produced on a very grand scale.

Conformable and unconformable stratification.—When strata rest one upon the other horizontally or with the same dip they are conformable. But strata are said to be unconformable when one series is so placed over another that the planes of

Fig. 78.



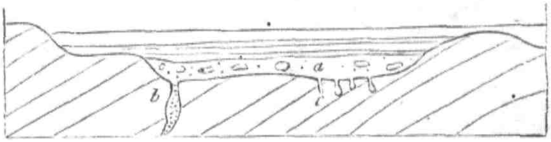
Unconformable junction of old red sandstone and Silurian schist at the Sicarr Point, near St. Abb's Head, Berwickshire.

the superior repose on the edges of the inferior (see fig. 78). In this case it is evident that a period had elapsed between the production of the two sets of strata, and that, during this interval, the older series had been tilted and disturbed. Afterwards the upper series accumulated, in horizontal strata, upon it. If these superior beds, *d d*, fig. 78, are also inclined, it is plain that the lower strata, *a a*, have been twice displaced—first, before the deposition of the newer beds, *d d*, and a second time when the same strata were upraised out of the sea, and thrown slightly out of the horizontal position.

It often happens that in the interval between the deposition of two sets of unconformable strata, the inferior rock has not only been denuded, but drilled by perforating shells. Thus, for example, at Autreppe and Gusigny, near Mons, beds of an ancient (primary or palæozoic) limestone, highly inclined, and often bent, are covered with horizontal strata of greenish and whitish

marls of the Cretaceous formation (fig. 79). The lowest, and therefore the oldest, bed of the horizontal series is usually the

Fig. 79.

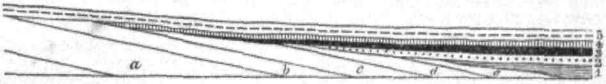


Junction of unconformable strata near Mons, in Belgium.

sand and conglomerate, *a*, in which are rounded fragments of stone, from an inch to two feet in diameter. These fragments have often adhering shells attached to them, and have been bored by perforating mollusca. The solid surface of the inferior limestone has also been bored, so as to exhibit cylindrical and pear-shaped cavities, as at *c*, the work of saxicavous mollusca; and many rents, as at *b*, which descend several feet or yards into the limestone, have been filled with sand and shells, similar to those in the stratum *a*.

Overlap of strata.—Strata are said to overlap when an upper bed extends beyond the limits of a lower one. Sediment

Fig. 80.



Overlap of strata.

a b c d e, Jurassic rocks. 1. Wealden. 2. Lower greensand. 3. Gault. 4. Upper greensand. 5. Chalk. (From Jukes-Brown, Phys. Geol. p. 388.)

spread over a region of subsidence has the area of deposit gradually increased, and the newest formed strata will overlap the next below them. Thus, as shore lines have subsided, shallow-water marine deposits have crept over the land, and as subsidence has progressed, deep-water deposits have come upon these last, and extended farther. Unconformity thus happens when one set of strata rest upon others with a different angle of dip, and lapse of time is indicated between the deposition of the last lamina of the lower and the first one of the upper stratum. When overlap is noticed, lapse of time and alterations in the physical geography of the area are inferred to have taken place between the deposition of successive strata; and this is more fully appreciated when erosion of a lower stratum is observed

beneath a super-imposed one. These lapses of time, both great and small, accompanied 'physical breaks.'

It is found that when two series of strata are unconformable or overlap, their fossils differ considerably. This is termed a palæontological break, and it may be slight or very nearly absolute. These breaks occur between all the great formations, and indicate the endings and beginnings of epochs, ages, and aspects of nature.

CHAPTER VI.

Denudation, disintegration of rocks and removal of products—Subaërial and marine denudation—Agents of denudation and their methods of action—Special action of wind and running water in the formation of Valleys, Cañons, Escarpments, Alluvium, and Loess—Littoral and submarine denudation—Great shoals—Needles, Inland sea cliffs—Results of denudation.

DENUDATION, which has been occasionally spoken of in the preceding chapters, is the disintegration of the earth's surface and the removal of the products by water in motion, whether of rivers or of the waves and currents of the sea, and by wind, and the consequent laying bare of some inferior rock. This operation has exerted an influence on the structure of the earth's crust as universal and important as sedimentary deposition itself; for denudation is the necessary antecedent of the production of all new strata of mechanical origin. The formation of every new deposit by the transport of sediment and pebbles, necessarily implies that there has been, somewhere else, a grinding down of rock into rounded fragments, sand, or mud, equal in quantity to the new strata. All deposition, therefore, except in the case of a shower of volcanic ashes, and the outflow of lava, and the growth of certain organic formations, is the sign of former superficial waste, or of that going on contemporaneously, and to an equal amount, elsewhere. The gain at one point is no more than sufficient to balance the loss at some other. Here a hill has been lowered, there a ravine or valley has been deepened. Here the depth of the sea has been augmented by the removal of a sand-bank during a storm, there its bottom has been raised and shallowed by the accumulation on its bed of the same sand transported from the bank.

When we see a stone building, we know that somewhere, far or near, a quarry has been opened. The courses of stone in the building may be compared to successive strata, the quarry to a ravine or valley which has suffered denudation. As the strata,

like the courses of hewn stone, have been laid one upon another gradually, so the excavation both of the valley and quarry has been gradual. To pursue the comparison still farther, the superficial heaps *of mud, sand, and gravel, usually called alluvium*, may be likened to the rubbish of a quarry which has fallen upon the road between the quarry and the building, so as to lie scattered at random over the ground.

But we occasionally find in a conglomerate, large rounded pebbles of an older conglomerate, which had previously been derived from a variety of different rocks. In such instances we are reminded that strata have been formed by the deposition of de[illegible]materials worn from older strata, and have been curved and elevated into hills and mountains. These in their turn have been worn down by the agents of denudation. In such cases it is evident that the same materials have been in very different conditions and positions, over and over again during the mutations which have affected the surface of the globe. Denudation and re-deposition have persisted ever since the earth's crust has been covered by an atmosphere, and has had its rivers and seas.

Denudation may be divided into subaërial and marine, and the agents which produce it are the sun's heat, cold, frost, the atmosphere, rain, rivers and the sea.

Subaërial denudation.—The sun acts on rocks by heating them, and when the component minerals expand differently with heat, and contract differently as they become cold, when the influence of the sun is at an end, *disintegration proceeds.* The sun dries clay, for instance, at the surface, and enables other agents to act. The alternations of heat and cold are attended by very remarkable results on rocks, brittleness being often produced. Prolonged cold, and especially with the aid of frost, moisture being present, is a great destroyer of the surface down to some depth, and the principal cause is the expansion of the water during the assumption of the crystalline state of ice. The atmosphere acts chemically and mechanically, and is assisted by the moisture it contains. Weathering of rocks by the carbonic acid of the air is assisted by the removal of the bicarbonates by rain and wind. The rapidity with which inscriptions on monuments in churchyards become effaced, when compared with similar records placed within the church, has often been pointed out as a striking illustration of the process of disintegration.

Professor Milne has shown how the sand-blast erodes the Arabian Wadys, scrubs the rocks, and removes the worn-off grains; and there are many examples of wind-borne and wind-wrecked rocks on every sea coast.

'Weathering' is often very conspicuous in crystalline rocks, such as granite and most volcanic rocks, which are composed of several mineral elements. Through the decomposition of the felspar and other minerals most liable to be chemically affected by air and rain, so hard rock as basalt sometimes crumbles to pieces, and it may be dug with a spade. Some of the most fertile districts in Italy and France owe their riches to the scoriæ and lava that once issued in a molten condition from the crater of Vesuvius and the volcanoes of Auvergne, destroying all the vegetation around, but which since then have cooled and crumbled into dust.

In desert regions, where no rain falls, or where, [illegible]rts of the Sahara, the soil is so salt as to be without any covering of vegetation, clouds of dust and sand attest the power of the wind to cause the shifting of the unconsolidated or disintegrated rock.

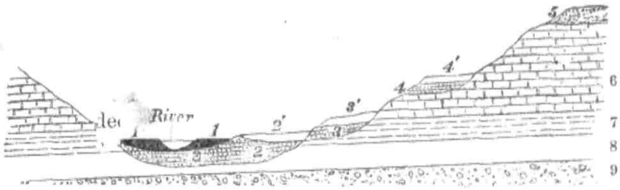
In examining volcanic countries I have been much struck with the great superficial changes brought about by this power in the course of centuries. The higher peak of Madeira is about 6,050 feet above the sea, and consists of the skeleton of a volcanic cone now 250 feet high, the beds of which once dipped from a centre in all directions at an angle of more than 30°. The summit is formed of a dike of basalt with much olivine, fifteen feet wide, apparently the remains of a column of lava which once rose to the crater. Nearly all the scoriæ of the upper part of the cone have been swept away, those portions only remaining which were hardened by the contact or proximity of the dike. While I was myself on this peak on January 25, 1854, I saw the wind, though it was not stormy weather, removing sand and dust derived from the decomposing scoriæ. There had been frost in the night, and some ice was still seen in the crevices of the rock.

On the highest platform of the Grand Canary, at an elevation of 6,000 feet, there is a cylindrical column of hard lava, from which the softer matter has been carried away; and other similar remnants of the dikes of cones of eruption, attest the denuding power of the wind at points where running water could never have exerted any influence. The waste effected by wind, aided by frost and snow, may not be trifling, even in a single winter, and, when multiplied by centuries, may become indefinitely great.

Action of running water.—Rain carries off the products of denudation to a certain extent, and removes them to streams and rivers. Running water moving stones along erodes, and deposition occurs eventually. Perhaps the most striking illustrations of

the erosive power of water are to be found in those valleys on both sides of which the same strata are seen following each other in the same order, and having the same mineral composition, and fossil contents. We may observe, for example, several

Fig. 81.



1. Peat.
2. Gravel of modern river.
2'. Loam of brick-earth (loess) of same age as 2, formed by inundations of the river.
3. Lower-level valley gravel.
3'. Loam of same age.
4. Higher-level valley gravel.
4'. Loam of same age.
5. Upland gravel of various kinds and periods.
6, 7, 8, 9. Older rocks.

formations, as Nos. 6, 7, 8, 9, in the accompanying diagram (fig. 81); No. 9, conglomerate; No. 8, clay; No. 7, grit; and No. 6, limestone, each repeated in the same order on either side of the valley. When we examine the subordinate parts of these four formations, we find, in like manner, distinct beds in each, corresponding, on the opposite sides of the valley, both in composition and order of position. No one can doubt that the strata were originally continuous, and that the portions which once connected the whole series have been swept away. A torrent on the side of a mountain produces similar interruptions; and when we make artificial cuts in lowering roads, we expose, in like manner, corresponding beds on either side. But in nature these appearances may occur in mountains several thousand feet high, and separated by intervals of many miles or leagues in extent.

The mode in which these hollows have been excavated, is well shown in many of the valleys of Western Europe and England where 'high and low level' river gravels occur. These appear in the form of terraces, or banks, at successive heights above the present level of the stream (fig. 81), and consist of a stratified formation of gravel, sand, and mud similar to that which is being deposited by the river whenever it overflows its banks. Like the recent alluvium, the gravel of the terraces frequently contains freshwater shells, and the bones and teeth of land animals, such as are liable to be washed into the stream during floods. As the material of all these gravel banks must

originally have been deposited by the river, it is clear that when the terrace at the highest level (No. 4) was being formed, it must have been part of the alluvium spread over what was then the lowest part of the valley. But the river has since deepened its channel, and left, above the reach of its water, a portion (No. 3) of the gravel it had formerly deposited. At this lower level new beds of gravel and sand were spread over the bottom of the valley, and out of these new terraces have been carved as the river continued to deepen its bed.

In general, it is only when rivers are swollen by heavy rain that any considerable quantity of solid matter is removed by their waters. At these times they frequently undermine their banks and precipitate vast masses of earth into the stream; these are rapidly washed away, while in the bed of the river fine gravel and larger fragments of loose stone are swept along, as the transporting power of the current is intensified with each addition to its volume.

But the erosive power of rivers would be comparatively insignificant if it were not aided by other causes, by means of which the hard and compact masses of rock, composing so great a part of the earth's crust, are reduced to fragments capable of being easily removed. All the subaërial agents of denudation tend to excavate the ordinary river valley, but cañons, which are deep gorges and ravines, with perpendicular sides, have been excavated by the unassisted power of rivers.

It must be remembered that rivers are mostly very old channels, and that in many instances they have lasted during the epoch of mountain formation which determined their existence, and ever since. Lowering of the surface, the formation of all the features of the hills, and the production of deep river gorges have progressed slowly and variably, but the main drainage has lasted on.

In considering the erosive power of rivers, it must be remembered that some are now 'taking-off' rivers, and others are 'depositing,' and that the oscillation or meandering of streams from side to side in their flood plains, has been and is an important factor in getting rid of gravels and muds.

Denuding power of rivers affected by rise or fall of land.—It has long been a matter of common observation that most rivers are now cutting their channels through alluvial deposits of greater depth and extent than could ever have been formed by the present streams. From this fact it has been inferred that rivers in general have grown smaller, or become less liable to be flooded than formerly. It may be true that in the history of almost every country, the rivers have been both larger

and smaller than they are at the present moment. For the rain-fall in particular regions varies according to climate and physical geography, and is especially governed by the elevation of the land above the sea, or its distance from it, and other conditions equally fluctuating in the course of time. But the phenomenon alluded to *may sometimes be accounted for by oscillations in the* level of the land, experienced since the existing valleys originated, even where no marked diminution in the quantity of rain and in the size of the rivers has occurred.

Suppose, for example, part of a continent, comprising within it a large hydrographical basin like that of the Mississippi, to subside several inches or feet in a century. It will rarely happen that the rate of subsidence will be everywhere equal, and in many cases the amount of depression in the interior will regularly exceed that of the region nearer the sea. Whenever this happens, *the fall of the waters flowing from the upland* country will be diminished, and each tributary stream will have less power to carry its sand and sediment into the main river, and the main river less power to convey its annual burden of transported matter to the sea. All the rivers, therefore, will proceed to fill up their ancient channels partially, and, during frequent inundations, will raise their alluvial plains by new deposits. If, then, the same area of land be again upheaved to its former height, the fall, and consequently the velocity, of every river will begin to augment. Each river then will be less given to overflow its alluvial plain ; and its power of carrying earthy matter seaward, and of scouring out and deepening its channel, will be sustained, until, after a lapse of years, a new channel or valley will be found to have been eroded through a fluviatile formation of comparatively modern date. The surface of what was once the river-plain at the period of greatest depression, will then remain fringing the valley sides in the form of a terrace apparently flat, but in reality sloping down with the general inclination of the river. Everywhere this terrace will present cliffs of gravel and sand, facing the river. That such a series of movements has actually taken place in the main valley of the Mississippi and in its tributary valleys during oscillations of level I have endeavoured to show in my description of that country ; and the freshwater shells of existing species and bones of land quadrupeds, partly of extinct races, preserved in the terraces of fluviatile origin, attest the exclusion of the sea, during the whole process of filling up and partial re-excavation.

Escarpments are the abrupt faces of rocks of various kinds which resemble sea-cliffs, far inland. They may extend for

many miles and bound many valleys, and have more or less precipitous faces. They are due to subaërial denudation, and are distinct from cliffs due to marine action.

I formerly supposed that the steep line of cliff-like slopes seen along the outcrop of the chalk, when we follow the edge of the North or South Downs, was due to marine action; but Sir A. Ramsay has shown [1] that the present outline of the physical geography is more in favour of the idea of the escarpments having been due to gradual waste since the rocks were exposed in the atmosphere, and to the action of rain and rivers.

Mr. Whitaker has given a good summary of the grounds for ascribing these apparent sea-cliffs to waste in the open air.[2] 1. There is an absence of all signs of ancient sea-beaches or littoral deposits at the base of the escarpment. 2. Great inequality is observed in the level of the base line. 3. The escarpments do not intersect a series of distinct rocks like sea-cliffs, but are always confined to the boundary line of the same formation. 4. There are sometimes different contiguous and parallel escarpments—those, for example, of the greensand and chalk—which are so near each other, and occasionally so similar in altitude, that we cannot imagine any existing archipelago, if converted into dry land, to present a similar outline.

The above theory is by no means inconsistent with the opinion that the limits of the outcrop of the chalk and greensand, which the escarpments now follow, were originally determined by marine denudation. When the south-east of England last emerged from beneath the level of the sea, it was acted upon, no doubt, by thetide, waves, and currents, and the chalk would form, from the first, a mass projecting above the more destructible clay called gault. Still the present escarpments so much resembling sea-cliffs have no doubt, for reasons above stated, derived their most characteristic features subsequently to emergence, from subaërial waste by rain and rivers.

The vast results of denudation in past time, are exhibited in a most impressive manner in those districts where we see some of the older strata of the earth appearing at the surface, as, for example, in the middle of an anticlinal curve (fig. 68), on either side of which rest a long series of succeeding and conformable strata. The newer beds must once have arched over the whole area, and have been stripped off, before the older strata could have been laid bare.

In the 'Memoirs of the Geological Survey of Great Britain' (vol. i.), Sir Alex. Ramsay has shown that the missing beds,

[1] Physical Geology and Geography of Great Britain, p. 337 *et seq.* 1878.
[2] Geol. Mag. vol. iv. p. 483.

removed from the summit of the Mendips, must have been nearly a mile in thickness; and he has pointed out considerable areas in South Wales and some of the adjacent counties of England, where a series of primary (or palæozoic) strata, not less than 11,000 feet in thickness, have been stripped off. All these materials have of course been transported to new regions, and have entered into the composition of more modern formations. It is clear that such old rocks, mostly formed of mud and sand, and consolidated, were the monuments of denuding operations, which must have taken place at some of the remotest periods of the earth's history yet known to us. For whatever has been given to one area must always have been borrowed from another; a truth which, obvious as it may seem when thus stated, must be repeatedly impressed on the student's mind, because in many doubtful geological speculations, it has been wrongly stated that the crust of the earth has been always growing thicker in consequence of the accumulation, period after period, of sedimentary matter, as if the new strata were not always produced at the expense of pre-existing rocks, stratified or unstratified.

It is well known that deltas are forming at the mouths of some large rivers, and the land is encroaching upon the sea; these deltas are monuments of recent denudation and deposition; and it is obvious that if the mud, sand, and gravel were taken from them and restored to the continents, they would fill up a large part of the gulleys and valleys which are due to the excavating and transporting power of torrents and rivers. By duly reflecting on the fact, that all deposits of mechanical origin imply the transportation from some other region, whether contiguous or remote, of an equal amount of solid matter, we perceive that the stony exterior of the planet must always have grown thinner in one place, whenever, by accessions of new strata, it was acquiring thickness in another.

Alluvium.—Between the superficial covering of vegetable mould and the subjacent rock there usually intervenes, in every district, a deposit of loose gravel, sand, and mud, to which when it occurs in valleys, the name of alluvium has been popularly applied. The term is derived from *alluvio*, an inundation, or *alluo*, to wash, because the pebbles and sand commonly resemble those of a river's bed, or the mud and gravel washed over low lands by a flood.

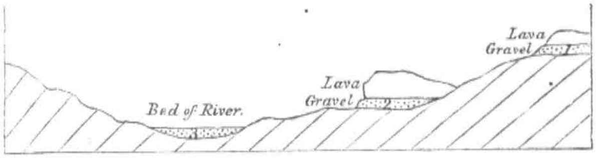
In the course of those changes in physical geography which may take place during the gradual emergence of the bottom of the sea and its conversion into dry land, any spot may either have been a sunken reef, or a bay, or estuary, or sea-shore, or the bed

of a river. The drainage, moreover, may have been deranged again and again by earthquakes, during which temporary lakes may have been caused by landslips, and partial deluges occasioned by the bursting of the barriers of such lakes. For this reason it would be unreasonable to hope that we should ever be able to account for all the alluvial phenomena of each particular country, seeing that the causes of their origin are so various. Besides, the last operations of water have a tendency to disturb and confound together all pre-existing alluviums. Hence we are always in danger of regarding as the work of a single era, and the effect of one cause, what has in reality been the result of a variety of distinct agents, during a long succession of geological epochs. Much useful instruction may therefore be gained from the exploration of a country like Auvergne, where the superficial gravel of very different eras happens to have been preserved and kept separate by sheets of lava, which were poured out, one after the other, at periods when the denudation, and probably the upheaval, of rocks were in progress. That region had already acquired in some degree its present configuration before any volcanoes were in activity, and before any igneous matter was superimposed upon the granitic and fossiliferous formations. The pebbles therefore in the older gravels are exclusively constituted of granite and other fundamental rocks; and afterwards, when volcanic vents burst forth into eruption, those earlier alluviums were covered by streams of lava, which protected them from intermixture with gravel of subsequent date. In the course of ages, a new system of valleys was excavated, so that the rivers ran at lower levels than those at which the first alluviums and sheets of lava were formed. When, therefore, fresh eruptions gave rise to new lava, the melted matter was poured out over lower grounds; and the gravel of these plains differed from the first or upland alluvium, by containing in it rounded fragments of various volcanic rocks, and often fossil bones belonging to species of land animals different from those which had previously flourished in the same country and from any others which had been buried in older gravels.

The annexed drawing (fig. 82) will explain the different heights at which beds of lava and gravel, each distinct from the other in composition and age, are observed, some on the flat tops of hills 700 or 800 feet high, others on the slope of the same hills, and the newest of all in the channel of the existing river, where there is usually gravel alone, although in some cases a narrow strip of solid lava shares the bottom of the valley with the river.

The proportion of extinct species of quadrupeds is more numerous in the fossil remains of the highest gravel than in that lower down; and in the bed of the river they agree with

Fig. 82.



Lavas of Auvergne resting on alluviums of different ages.

those of the existing fauna. The usual absence or rarity of organic remains in beds of loose gravel and sand is partly owing *to the friction which originally ground down the rocks into small* fragments, and partly to the porous nature of alluvium, which allows the free percolation through it of rain-water, and promotes the decomposition and removal of fossil remains.

The loose transported matter on the surface of a large part of the land now existing in the temperate and arctic regions of the northern hemisphere, must be regarded as being in a somewhat exceptional state, in consequence of the important part which ice has played in comparatively modern geological times. This subject will be more specially alluded to, when we describe the deposits called 'glacial.'

Marine denudation.—The waves of the sea when driven by storms are continually wearing away the coastline, in some cases undermining the cliffs and hollowing out deep caverns. Cliffs wear back and leave low fore shores, which are planed more or less level by the waves and tides. Part of the action of the waves between high and low water mark must be included in subaërial denudation, more especially as the undermining of cliffs by the waves is facilitated by land-springs, and these often lead to the sliding down of great masses of land into the sea. But the destruction wrought by these means would soon come to an end if the force of the waves and the tides did not break up whatever is brought within their reach, and, by sweeping the fragments to deep water, prepare the way for renewed gains upon the land.

Though the denuding power of the waves is confined within the narrow limits between tide-marks, the phenomena of our raised beaches and submerged forests indicate oscillations of level, and as such movements are very gradual, they must have given repeated opportunities to the breakers to denude the land

which was again and again exposed to their fury, although it is evident that the submergence was sometimes effected in such a manner as to allow the trees which border the coast not to be carried away.

Ground-swell waves are important agents of denudation when they come into shallow water. Scott Russell showed that a single roller of the ground swell 20 feet high falls with a pressure of a ton on every square foot, and Stevenson stated that the force of the breakers of the Atlantic on the sea-coasts of Britain was 611 lbs. per square foot in summer, and 2,086 lbs. in winter. It is stated that ground swell will influence the bottom at 200 fathoms. But Delesse has proved that engineering operations are scarcely disturbed at a greater depth than 16·4 feet in the Mediterranean Sea, and 26·24 feet in the Atlantic. In the English Channel the bottom is stirred up at 130 feet, 164 feet in the Mediterranean, and 650 feet in the Ocean. The abyssal depths are very motionless, and are areas of deposition. All modern research tends to show that the eroding action of the sea is restricted to within a few fathoms of the shore.

The sea removes the products of its own erosion, and most of the results of subaërial denudation. The mud of rivers sinks sooner or later when in contact with the sea, and clays readily sink in salt water; but it appears that deep-sea deposits remote from land, are singularly exempt from land deposits. The vast volumes of soluble matters brought down by the rivers into the sea contribute to the calcareous skeletons of a host of marine organisms.

The along-shore deposits, as they are termed, are shingle beds and boulder deposits, and they are rarely stationary. Derived from the fall of cliffs and worn by the rolling of water, and by impact with other stones, the boulders become pebbles, and the sand, the result of this wearing, is carried off by tide and currents. Finally, the pebbles collect in masses, or are still further worn. In the first instance they resemble many geological formations, and, were they cemented, would be conglomerates. The sand, the result of the wearing of the boulders and pebbles, becomes spread out in layers, which resemble the sandstones of old with rain prints and ripple markings.

Submarine denudation.—When we attempt to estimate the amount of submarine denudation, we become sensible of the disadvantage under which we labour from our habitual incapacity of observing the action of marine currents on the bed of the sea. We know that the agitation of the waves, even during storms, diminishes at a rapid rate, so as to become very insig-

nificant at the depth of a few fathoms, but when large bodies of water are transferred by a current, from one part of the ocean to another, they are known to maintain at great depths such a velocity as must enable them to remove the finer, and sometimes even the coarser, materials of the rocks over which they flow. As the Mississippi when more than 150 feet deep can keep open its channel and even carry down gravel and sand to its delta, the surface velocity being not more than two or three miles an hour, so a gigantic current like the Gulf Stream, equal in volume to many hundred Mississippis, and having in parts a surface velocity of more than three miles, may act as a propelling and abrading power at still greater depths. But the efficacy of the sea as a denuding agent, geologically considered, is not dependent on the power of currents to preserve at great depths a velocity sufficient to remove sand and mud, because, even where the deposition or removal of sediment is not in progress, the depth of water does not remain constant throughout geological time. Every page of the geological record proves to us that the relative levels of land and sea, and the position of the ocean and of continents and islands, have been always varying, and we may feel sure that some portions of the submarine area are now rising and others sinking. The force of tidal and other currents and of the waves during storms was sufficient to prevent the emergence of many lands, even though they were undergoing continual upheaval. It is not an uncommon error to imagine that the waste of sea-cliffs affords the measure of the amount of marine denudation, of which it probably constitutes an insignificant portion.

Dogger-bank.—That great shoal called the Dogger-bank, about sixty miles east of the coast of Northumberland, and occupying an area about as large as Wales, has nowhere a depth of more than ninety feet, and in its shallower parts is less than forty feet under water. It might contribute towards the safety of the navigation of our seas to form an artificial island, and to erect a lighthouse on this bank; but no engineer would be rash enough to attempt it, as he would feel sure that the ocean in the first heavy gale would sweep it away as readily as it does every temporary shoal that accumulates from time to time around a sunk vessel on the same bank.[3]

No observed geographical changes in historical times entitle us to assume that where upheaval may be in progress it proceeds at a rapid rate. Three or four feet rather than as many yards in a century may probably be as much as we can reckon upon in our speculations; and if such be the case, the continuance of

[3] Principles, 10th ed. vol. i. p. 569.

the upward movement might easily be counteracted by the denuding force of such currents aided by such waves as during a gale are known to prevail in the German Ocean. What parts of the bed of the ocean are stationary at present, and what areas may be rising or sinking, is a matter of which we are very ignorant, as the taking of accurate soundings is but of recent date.

Newfoundland-bank.—The great bank of Newfoundland may be compared in size to the whole of England. This part of the bottom of the Atlantic is surrounded on three sides by a rapidly deepening ocean, the bank itself being from twenty to fifty fathoms (or from 120 to 300 feet) under water. We are unable to determine by the comparison of different charts, made at distant periods, whether it is undergoing any change of level, but if it be gradually rising we cannot anticipate on that account that it will become land, because the breakers in an open sea would exercise a prodigious force even on solid rock brought up to within a few yards of the surface. We know, for example, that when a new volcanic island rose in the Mediterranean in 1831, the waves were capable in a few years of reducing it to a sunken rock.

In the same way currents which flow over the Newfoundland-bank a great part of the year at the rate of two miles an hour, and are known to retain a considerable velocity to near the bottom, may carry away all loose sand and mud and make the emergence of the shoal impossible, in spite of the accessions of mud, sand, and boulders derived occasionally from melting icebergs which, coming from the northern glaciers, are frequently stranded on various parts of the bank. They must often leave at the bottom large erratic blocks which the marine currents may be incapable of moving.

'Needles' and 'No Man's Lands' are portions of cliffs unworn down by the sea; they indicate the former extension of the land up to and beyond them seawards. They are, as it were, outlines of the strata which have been worn away, and which are recognised in the main cliffs of the land. Earth pillars with stones on their tops, are relics of the country worn away all around them.

Inland sea-cliffs.—In countries where hard limestone rocks abound, inland cliffs have often retained the characters which they acquired when they constituted the boundary of land and sea. Thus, in the Morea, no less than three or even four ranges of cliffs are well preserved, rising one above the other at different distances from the actual shore, the summit of the highest and oldest occasionally attaining 1,000 feet in elevation. A consoli-

dated beach with marine shells is usually found at the base of each cliff, and a line of old shore caverns.

But the beginner should be warned not to expect to find evidence of the former sojourn of the sea on all those lands which we are nevertheless sure have been submerged at periods comparatively modern; for notwithstanding the enduring nature of the marks left by littoral action on some rocks, especially limestones, we can by no means detect sea-beaches and inland cliffs everywhere. On the contrary, they are, upon the whole, extremely partial, and are often entirely wanting in districts composed of argillaceous and sandy formations, which must, nevertheless, have been upheaved at the same time, and by the same intermittent movements, as the adjoining harder rocks.

CHAPTER VII.

JOINT ACTION OF DENUDATION, UPHEAVAL, AND SUBSIDENCE IN REMODELLING THE EARTH'S CRUST.

How we obtain an insight at the surface of the arrangement of rocks at great depths—Why the height above sea-level of the successive strata in a given region is so disproportionate to their thickness—Computation of the average annual amount of subaërial denudation—Antagonism of the internal energies of the globe to those acting on its surface—How far the transfer of sediment from the land to a neighbouring sea-bottom may affect subterranean movements—Permanence and mutability of continental and oceanic areas.

How we obtain an insight at the surface of the arrangement of rocks at great depths.—The reader has been already informed that in the structure of the earth's crust we often find proofs of the direct superposition of marine to freshwater strata, and also evidence of the alternation of deep-sea and shallow-water formations. Sedimentary deposits cannot become thick if exposed to concurrent denudation. Darwin suggested years ago that all deep sediments accumulated during subsidence of their area. In order to explain how such a series of rocks could be made to form our present continents and islands, we have not only to assume that there have been alternate upward and downward movements of great vertical extent, but that the upheaval in the areas which we at present inhabit has, in later geological times, sufficiently predominated over subsidence so as to cause these portions of the earth's crust to be land instead of sea. The sinking down of a delta beneath the sea-level may cause strata

of fluviatile or even terrestrial origin, such as peat with trees proper to marshes, to be covered by deposits of deep-sea origin. There is also no limit to the thickness of mud and sand which may accumulate in shallow water, provided that fresh sediment is brought down from the wasting land at a rate corresponding to that of the sinking of the bed of the sea.

The succession of strata here alluded to would be consistent with the occurrence of gradual downward and upward movements of the land and bed of the sea without any disturbance of the horizontality of the several formations. But the arrangement of rocks composing the earth's crust differs materially from that which would result from a mere series of radial vertical movements. Had the internal energies of the globe only produced such movements, and had the stratified rocks been first formed beneath the sea and then raised above it, without any lateral compression, the geologist would never have obtained an insight into the monuments of various ages, some of extremely remote antiquity.

What we have said in Chapter V. of dip and strike, of the folding and inversion of strata, of anticlinal and synclinal flexures, and in Chapter VI. of denudation at different periods, whether subaërial or submarine, must be understood before the student can comprehend what may at first seem to him an anomaly, but which it is his business particularly to understand. I allude to the small height above the level of the sea attained by strata, often many miles in thickness, and about the chronological succession of which, in one and the same region, there is no doubt whatever. Had stratified rocks in general remained horizontal, the waves of the sea would have been enabled during oscillations of level to plane off entirely the uppermost beds as they rose or sank during the emergence or submergence of the land. But the occurrence of a series of formations of widely different ages, all remaining horizontal and in conformable stratification, is exceptional, and for this reason the total annihilation of the uppermost strata has rarely taken place. We owe, indeed, to the side to side movement produced by tangential thrust those anticlinal and synclinal curves of the beds already described (fig. 55, p. 51), which, together with denudation, subaërial and submarine, enable us to investigate the structure of the earth's crust many miles below those points which the miner can reach under other circumstances. I have already shown in fig. 78, p. 68, how, at St. Abb's Head, a series of strata of indefinite thickness may become vertical, and then denuded, so that the edges of the beds alone shall be exposed to view, the altitude of the upheaved ridges being reduced to

a moderate height above the sea-level. The breadth of an exposed edge of a stratum is equivalent to its height were the horizontal position maintained. It may be observed that, although the incumbent strata of Old Red Sandstone (*d d′*) are nearly horizontal, yet they will in other places be found so folded as to present vertical strata, the edges of which are abruptly cut off, as in 2, 3, 4 on the right-hand side of the diagram, fig. 55, p. 51.

Why the height above sea-level of the successive strata in a given region is so disproportionate to their thickness.—We cannot too distinctly bear in mind how dependent we are, for our power of consulting the different pages of those stony records of which the crust of the globe is composed, on the joint action of the internal energies and agents of denudation, the one in disturbing the original position of rocks, and the other in destroying large portions of them. Why, it may be asked, if the ancient bed of the sea has been in many regions uplifted to the height of two or three miles, and sometimes twice that altitude, and if it can be proved that some single formations are of themselves two or three miles thick, do we so often find several important groups resting one upon the other, yet attaining only the height of a few hundred feet above the level of the sea?

The American geologists, after carefully studying the Alleghany or Appalachian mountains, have ascertained that the older fossiliferous rocks of that chain (from the Silurian to the Carboniferous inclusive) are not less than 42,000 feet thick, and if they were now superimposed on each other in the order in which they were deposited, they ought to equal in height the Himalayas with the Alps piled upon them. Yet they rarely reach an altitude of 5,000 feet, and their loftiest peaks are no more than 7,000 feet high. The Carboniferous strata forming the highest member of the series, and containing beds of coal, can be shown to be of shallow-water origin, or even sometimes to have originated in swamps in the open air. But what is more surprising, the lowest part of this great Palæozoic series, instead of having been deposited at the bottom of an abyss more than 40,000 feet deep, consists of sediment (the Potsdam sandstone), evidently spread out on the bottom of a shallow sea on which ripple-marked sands were occasionally formed. This vast thickness of 40,000 feet is *estimated* by measuring the denuded edges of the vertical strata forming the parallel folds into which the originally horizontal Silurian and Carboniferous rocks had been forced, and which 'crop out' at the surface.

A like phenomenon is exhibited in every mountainous country,

as, for example, in the European Alps; but we need not go farther than the north of England for its illustration. Thus in Lancashire and central England the thickness of the Carboniferous formation, including the Millstone Grit and Yoredale beds, is computed to be more than 18,000 feet; to this we may add the Mountain Limestone, at least 2,000 feet in thickness, and the overlying Permian and Triassic formations, 3,000 or 4,000 feet thick. How then does it happen that the loftiest hills of Yorkshire and Lancashire, instead of being 24,000 feet high, never rise to 3,000 feet? The denuded edges of the strata, which are in great curves, are measurable, but the bulk of the thickness is below sea-level.

A study of figs. 68 and 78 will explain the relation of the thickness of strata to their height above sea-level. It is evident that the denuded edges of very thick septa, which are in great curves, are measurable, and that the bulk of the deposit is hidden. Hence masses of stratified rocks may be several miles in thickness, yet the elevation attained may be not more than a mile above sea-level.

The proofs of lapse of time having occurred between consecutive strata, are unconformity, overlap, and erosion of the upper surface of the lower strata.

Computation of the average annual amount of subaërial denudation.—Mr. Croll in 1867, and again, with more exactness, in 1868, deduced from the latest measurement of the sediment transported by European and American rivers, the rate of subaërial denudation to which the surface of large continents is exposed, taking especially the hydrographical basin of the Mississippi as affording the best available measure of the average waste of the land. The conclusion arrived at in his able memoir,[1] was that the whole terrestrial surface is denuded at the rate of one foot in 6,000 years, and this opinion was simultaneously enforced by his fellow-labourer, Professor A. Geikie, who, being jointly engaged in the same line of inquiry, published a luminous essay on the subject in 1868.

The student, by referring to the 'Principles of Geology,'[2] may see that Messrs. Humphrey and Abbot, during their survey of the Mississippi, attempted to make accurate measurements of the proportion of sediment carried down annually to the sea by that river, including not only the mud held in suspension, but also the sand and gravel forced along the bottom.

It is evident that when we know the dimensions of the area which is drained, and the annual quantity of earthy matter

[1] Croll, Phil. Mag. 1868, p. 381.
[2] Vol. i. p. 454. 1872.

taken from it and borne into the sea, we can affirm how much on an average has been removed from the general surface in one year; and there seems no danger of our overrating the mean rate of waste by selecting the Mississippi as our example, for that river drains a country equal to more than half the continent of Europe, extends through twenty degrees of latitude, and therefore through regions enjoying a great variety of climate, and some of its tributaries descend from mountains of great height. The Mississippi is also more likely to afford us a fair test of ordinary denudation, because, unlike the St. Lawrence and its tributaries, there are no great lakes in which the fluviatile sediment is thrown down and arrested on its way to the sea. In striking a general average we have to remember that there are large deserts in which there is scarcely any rainfall, and tracts which are as rainless as parts of Peru, and these must not be neglected as counterbalancing others, in the tropics, where the quantity of rain is in excess. If then, argues Professor A. Geikie, we assume that the Mississippi is lowering the surface of the great basin which it drains at the rate of 1 foot in 6,000 years, 10 feet in 60,000 years, 100 feet in 600,000 years, and 1,000 feet in 6,000,000 years, it would not require more than about 4,500,000 years to wear away the whole of the North American continent, if its mean height is correctly estimated by Humboldt at 748 feet. And if the mean height of all the land now above the sea throughout the globe is 1,000 feet, as some geographers believe, it would only require six million years to subject a mass of rock equal in volume to the whole of the land to the action of subaërial denudation. It may be objected that the annual waste is partial, and not equally derived from the general surface of the country, inasmuch as plains, watersheds, and level ground at all heights remain comparatively unaltered; but this, as Professor A. Geikie has well pointed out, does not affect our estimate of the sum total of denudation. The amount remains the same, and if we allow too little for the loss from the surface of table-lands we only increase the proportion of the loss sustained by the sides and bottoms of the valleys, and *vice versâ*.[3]

These calculations are only valuable if it is true that the rainfall has not increased or diminished, and that the climate has always been the same.

Antagonism of hypogene force to the levelling power of running water.—In all these estimates it is assumed that the entire quantity of land above the sea-level remains on an average

[3] Trans. Geol. Soc. Glasgow, vol. iii. p. 169.

undiminished in spite of annual waste. Were it otherwise, the subaërial denudation would be continually lessened by the diminution of the height and dimensions of the land exposed to waste. I stated in 1830, in the 'Principles of Geology,'[4] that running water and volcanic action are two antagonistic forces; the one labouring continually to reduce the whole of the land to the level of the sea, the other to restore and maintain the inequalities of the crust on which the very existence of islands and continents depends. We must always bear in mind that it is not simply by upheaval that subterranean movements can counteract the levelling force of running water. For whereas the transportation of sediment from the land to the ocean or the upheaval of its bed would raise the general sea-level, the subsidence of the sea-bottom by increasing its capacity would check this rise and prevent the submergence of the land.

In the same way, the average height and area of the land can only be preserved if the increase occasioned by elevation in one part exceeds the loss by subsidence elsewhere by the amount removed by denudation from the whole surface of the land. It is only by considering the joint action of all the causes that determine the level of the sea and the height of the land that we can form some idea of the relation of these destroying and renovating energies.

I have, indeed, endeavoured to show that unless we assume that there is, on the whole, more subsidence than upheaval, we must suppose the diameter of the planet to be always increasing, by that quantity of volcanic matter which is annually poured out in the shape of lava or ashes, whether on the land or in the bed of the sea, and which is derived from the interior of the earth. The abstraction of this matter causes, no doubt, in some instances, subsidence. Moreover, it is probable that the globe has become smaller from contraction during secular cooling.

The action of energies within the earth in antagonising denudation by producing great curvings of the crust in past times is not a mere matter of conjecture. The student will see in Chapter XXIV. that we have proofs of Carboniferous forests hundreds of miles in extent which grew on the lowlands or deltas near the sea, and which subsided and gave place to other forests, until in some regions fluviatile and shallow-water strata with occasional seams of coal were piled one over the other, till they attained a thickness of many thousand feet. These have

[4] 1st ed. chap. x. p. 167. 1830. See also 11th ed. vol. i. chap. xv. p. 321. 1867.

often been preserved owing to their being forced into synclinal curves and removed out of the range of denudation.

It will be also seen in Chapter XXVI. that we have evidence of a rich terrestrial flora, the Devonian, even more ancient than the Carboniferous; while, on the other hand, the later Triassic, Oolitic, Cretaceous, and successive Tertiary periods have all supplied us with fossil plants, insects, or terrestrial mammalia; showing that, in spite of great oscillations of level and continued changes in the position of land and sea, the internal energies have maintained a due proportion of dry land. We may appeal also to freshwater formations, such as the Purbeck and Wealden, to prove that in the Oolitic and Neocomian eras there were rivers draining ancient lands in Europe in times when we know that other spaces, now above water, were submerged.

How far the transfer of sediment from the land to a neighbouring sea-bottom may affect subterranean movements.—It has been suggested that the stripping off by denudation of dense masses from one part of a continent and the delivery of the same into the bed of the ocean must have a decided effect in causing changes of temperature in the earth's crust below, or, in other words, in causing the subterranean isothermals to shift their position. If this be so, one part of the crust may be made to rise, and another to sink, by the expansion and contraction of the rocks, of which the temperature is altered. It is, however, probable that this transfer of sediment plays a very subordinate part in modifying those movements on which the configuration of the earth's crust depends. (See p. 54.)

Persistence and mutability of continental and oceanic areas.—If the thickness of more than 40,000 feet of sedimentary strata, before alluded to, in the Appalachians, proves a preponderance of downward movements of the sea-floor in Palæozoic times in a district now forming the eastern border of North America, it also proves, as before hinted, the continued existence and waste of some neighbouring continent, probably formed of Laurentian rocks, and situated where the Atlantic now prevails. Such an hypothesis would be in perfect harmony with the conclusions forced upon us by the study of the present configuration of our continents, the relation of their height to the depth of the oceanic basins; also to the considerable elevation and extent sometimes reached by drift containing shells of recent species, and still more by the fact of sedimentary strata, several thousand feet thick, as those of central Sicily, or such as flank the Alps and Apennines, containing fossil mollusca sometimes almost wholly identical with species still living.

Movements of 1,000 feet or more, would turn much land into

sea, and sea into land, in the continental areas and their borders; whereas oscillations of equal magnitude would have no corresponding effect in the bed of the ocean generally, believed as it is to have a mean depth of at least 12,000 feet. The greatest depths of the sea do not exceed the greatest heights of the land; it may, therefore, seem strange that the mean depth of the sea should exceed the mean height of the land twelve times, even taking the lowest estimate of the ocean depths as given by the late deep-sea soundings.[5] This apparent anomaly arises from the fact that the extreme heights of the land are exceptional and confined to a small part of its surface; while the ocean maintains its great depth over enormous areas.

It is evident that during the Glacial period there was a great subsidence of the land of the northern hemisphere down to a certain parallel of latitude. Since then elevation has occurred, and now many raised beaches are 1,000 to 1,200 feet above sea-level. Dana, following Darwin's theory of Atoll formation, terms the Atoll a memorial of a departed land, and considers that the great Pacific subsidence was contemporaneous with the post-glacial upheaval in the north.

From all that we know of the extreme slowness of the upward and downward movements which bring about even slight geographical changes, we may infer that it would require a great lapse of time to cause the submarine and supramarine areas to change places, even if the ascending movements in the one region and the descending in the other were continuously in one direction. But we have only to appeal to the structure of the Alps, where there are so many shallow and deep-water formations of various ages crowded into a limited area, to convince ourselves that mountain chains are the result of great oscillations of level. High land is not produced simply by uniform upheaval, but by a predominance of elevatory over subsiding movements. Where the ocean is extremely deep it is because the sinking of the bottom has been in excess, in spite of interruptions by upheaval.

Yet, persistent as may be the leading features of land and sea on the globe, they are not immutable. Some of the finest mud is doubtless carried to indefinite distances from the coast by marine currents, and we are taught by deep-sea dredgings that in clear water, at depths equalling the height of the Alps, organic beings may flourish, and their spoils slowly accumulate on the bottom. We also occasionally obtain evidence that submarine volcanoes are pouring out ashes and streams of lava in mid-ocean as well as on land (see 'Principles,' vol. ii. p. 64), and that

[5] Wyville Thomson, Depths of the Sea, p. 31. 1873.

wherever mountains like Etna, Vesuvius, and the Canary Islands are now the site of eruptions, there are signs of accompanying upheaval, by which beds of ashes full of recent marine shells have been uplifted many hundred feet. We need not be surprised, therefore, if we learn from geology that the continents and oceans were not always placed where they now are, although the imagination may well be overpowered when it endeavours to contemplate the quantity of time required for such revolutions.

We shall have gained a great step if we can approximate to the number of millions of years in which the average aqueous denudation going on upon the land would convey seaward a quantity of matter equal to the average volume of our continents, and this might give us a gauge of the minimum of hypogene energy necessary to counteract such levelling power of running water; but to discover a relation between these great agencies and the rate at which species of organic beings vary, is at present wholly beyond the reach of our computation, though perhaps it may not prove eventually to transcend the powers of Man.

CHAPTER VIII.

CHRONOLOGICAL CLASSIFICATION OF ROCKS.

Aqueous, aërial, plutonic, volcanic, and metamorphic rocks considered chronologically—Terms *Primary, Secondary, and Tertiary; Palæozoic,* Mesozoic, and Cainozoic explained—On the different ages of the aqueous rocks—Three principal tests of relative age: superposition, mineral character, and fossils—Change of mineral character and fossils in the same continuous formation—Proofs that distinct species of animals and plants have lived at successive periods—Distinct provinces of indigenous species—Great extent of single provinces—Similar laws prevailed at successive geological periods—Relative importance of mineral and palæontological characters—Test of age by included fragments—Frequent absence of strata of intervening periods—Tabular views of fossiliferous strata.

Chronology of rocks.—In the first chapter it was stated that the five great classes of rocks, the aqueous, the aërial, the volcanic, the plutonic, and the metamorphic, would each be considered not only in reference to their mineral characters, and mode of origin, but also to their relative age. In regard to the aqueous rocks, we have already seen that they are stratified, that some are calcareous, others argillaceous or siliceous, some made up of sand, others of pebbles; that some contain freshwater, others

marine fossils, and so forth; but the student has still to learn which rocks, exhibiting some or all of these characters, have originated at one period of the earth's history, and which at another.

To determine this point in reference to the fossiliferous formations is more easy than in any other class, and it is therefore the most convenient and natural method to begin by establishing a chronology for these strata, and then to refer as far as possible to the same divisions, the several groups of plutonic, volcanic, and metamorphic rocks. Such a system of classification is not only recommended by its greater clearness and facility of application, but is also best fitted to strike the imagination by bringing into one view the contemporaneous revolution of the inorganic and organic creations of former times. For the sedimentary formations are most readily distinguished by the different species of fossil animals and plants which they inclose, and of which one set after another has flourished and then disappeared from the earth in succession.

In the present work, therefore, the five great classes of rocks will form five parallel, or nearly parallel, columns in one chronological table. They will be considered as sets of monuments relating to contemporaneous, or nearly contemporaneous, series of events. Just as aqueous and fossiliferous strata are now formed in certain seas or lakes, while in other places volcanic rocks break out at the surface—so, at every era of the past, fossiliferous deposits and superficial igneous rocks were in progress contemporaneously with others of subterranean and plutonic origin, and some sedimentary strata were exposed to heat, pressure and chemical action, and made to assume a crystalline or metamorphic structure.

The early geologists gave to all the crystalline and non-fossiliferous rocks the names of primitive or Primary, under the idea that they were formed anterior to the appearance of life upon the earth; while the aqueous or fossiliferous strata were termed Secondary; and alluviums or other superficial deposits, Tertiary. The meaning of these terms has, however, been gradually modified with advancing knowledge, and they are now used to designate three great chronological divisions under which all geological formations can be classed, each of them being characterised by the presence of distinctive groups of organic remains rather than by any mechanical peculiarities of the strata themselves. If, therefore, we retain the term 'Primary,' it must not be held to designate a set of crystalline rocks some of which are believed by a few geologists to be even of Tertiary age, but it must be applied to all rocks older than the Secondary formations. Some

geologists, to avoid misapprehension, have introduced the term Palæozoic for primary, from παλαιον, 'ancient,' and ζωον, 'an organic being,' still retaining the terms secondary and tertiary ; Professor Phillips, for the sake of uniformity, has proposed Mesozoic, for secondary, from μεσος, 'middle,' &c. ; and Cainozoic, for tertiary, from καινος, 'recent,' &c. ; but the terms primary, secondary, and tertiary have the claim of priority in their favour, and are of corresponding value.

It may perhaps be suggested that some metamorphic strata, and some granites, may be anterior in date to the oldest of the primary fossiliferous rocks. This opinion is doubtless true, and will be discussed in future chapters ; but I may here observe, that when we arrange the five classes of rocks in five parallel columns in one table of chronology, it is by no means assumed that these columns are all of equal length ; one may begin at an earlier period than the rest, and another may come down to a later point of time, and we may not be yet acquainted with the most ancient of the primary fossiliferous rocks, or with the newest of the hypogene or netherformed.

Certainly changes must have been going on in the hypogene rocks during the whole of the great periods, but it is thought by many geologists that plutonic rocks, and the very schistose metamorphic rocks are never of late geological age.

For reasons already stated, I proceed first to treat of the aqueous or fossiliferous formations, considered in chronological order or in relation to the different periods at which they have been deposited.

Age of strata.—There are three principal tests by which we determine the age of a given set of strata : first, superposition ; secondly, mineral character ; and, thirdly, organic remains. Some aid can occasionally be derived from a fourth kind of proof, namely, the fact of one deposit including in it fragments of a pre-existing rock, by which the relative ages of the two may, even in the absence of all other evidence, be determined.

Superposition.—The first and principal test of the age of one aqueous deposit, as compared to another, is relative position. It has been already stated, that, where strata are horizontal, the bed which lies uppermost is the newest of the whole, and that which lies at the bottom the most ancient. So, of a series of sedimentary formations, they are like volumes of history, in which each writer has recorded the annals of his own times, and then laid down the book, with the last written page uppermost, upon the volume in which the events of the era immediately preceding were commemorated. In this manner a lofty pile of chronicles is at length accumulated ; and they are so arranged

as to indicate, by their position alone, the order in which the events recorded in them have occurred.

In regard to the crust of the earth, however, there are some regions where, as the student has already been informed, the beds have been disturbed, and sometimes extensively thrown over and turned upside down. (See pp. 51 to 69.) But an experienced geologist can rarely be deceived by these exceptional cases. When he finds that the strata are fractured, curved, inclined, or vertical, he knows that the original order of superposition must be doubtful, and he then endeavours to find sections in some neighbouring district where the strata are horizontal, or only slightly inclined. Here, the true order of sequence of the entire series of deposits being ascertained, a key is furnished for settling the chronology of those strata where the displacement is extreme.

Mineral character.—The same rocks may often be observed to retain for miles, or even hundreds of miles, the same mineral peculiarities, if we follow the planes of stratification, or trace the beds, if they be undisturbed, in a horizontal direction. But *if we pursue them vertically, or in any direction transverse to the* planes of stratification, this uniformity ceases almost immediately. In that case we can scarcely ever penetrate a stratified mass for a few hundred yards without beholding a succession of extremely dissimilar rocks, some of fine, others of coarse grain, some of mechanical, others of chemical origin; some calcareous, others argillaceous, and others siliceous. These phenomena lead to the conclusion, that rivers, wind, and marine currents have dispersed the same sediment over wide areas at one period, but at successive periods have been charged, in the same region, with very different kinds of matter. The first observers were so astonished at the vast spaces over which they were able to follow the same homogeneous rocks in a horizontal direction, that they came hastily to the opinion that the whole globe had been environed by a succession of distinct aqueous formations, disposed round the nucleus of the planet, like the concentric coats of an onion. But although, in fact, some formations may be continuous over districts as large as half of Europe, or even more, yet most of them either terminate wholly within narrower limits, or soon change their lithological character. Sometimes they thin out gradually, as if the supply of sediment had failed in that direction, or they come abruptly to an end, as if we had arrived at the borders of the ancient sea or lake which served as their receptacle. It no less frequently happens that they vary in mineral aspect and composition, as we pursue them horizontally. For example, we trace a limestone for a hundred

miles, until it becomes more arenaceous, and finally passes into sand, or sandstone. We may then follow this sandstone, already proved by its continuity to be of the same age, throughout another district a hundred miles or more in length.

Organic remains.—This character must be used as a test of *the age of a formation or of the contemporaneous origin of two* deposits in distant places, under very much the same restrictions as the test of *mineral composition.*

First, the same fossils may be traced over wide regions, if we examine strata in the direction of their planes, although by no means for indefinite distances. Secondly, while the same fossils prevail in a particular set of strata for hundreds of miles in a horizontal direction, we seldom meet with the same remains for many fathoms, and very rarely for several hundred yards, in a vertical direction, or a direction transverse to the strata. This fact has now been verified in almost all parts of the globe, and has led to a conviction that, at successive periods of the past, the same area of land and water has been inhabited by species of animals and plants even more distinct than those which now people the antipodes, or which now co-exist in the arctic, temperate, and tropical zones. It appears that from the remotest periods there has been ever a coming in of new organic forms, and an extinction of those which pre-existed on the earth : some species have endured for a longer, others for a shorter, time ; while none have ever re-appeared after once dying out. The law which has governed the succession of species, whether we adopt or reject the theory of transmutation, seems to be expressed in the verse of the poet,—

> Natura il fece, e poi ruppe la stampa.—ARIOSTO.
>
> Nature made him, and then broke the die.

And this circumstance it is which confers on fossils their highest value as chronological tests, giving to each of them, in the eyes of the geologist, that authority which belongs to contemporary medals in history.

The same cannot be said of each peculiar variety of rock ; for some of these, as red marl and red sandstone, for example, may occur at once at the top, bottom, and middle of the entire sedimentary series, exhibiting in each position so perfect an identity of mineral aspect as to be undistinguishable. Such exact repetitions, however, of the same mixtures of sediment have not often been produced, at distant periods, in precisely the same parts of the globe ; and, even where this has happened, we are not in any danger of confounding together the monuments

of remote eras, when we have studied their embedded fossils and their relative position.

Zoological provinces.—It was remarked that the same species of organic remains cannot be traced horizontally, or in the direction of the planes of stratification for indefinite distances. This might have been expected from analogy ; for when we inquire into the present distribution of living beings, we find that the habitable surface of the sea and land may be divided into a considerable number of distinct areas or provinces, each peopled by a peculiar assemblage of animals and plants. The extent of these separate divisions and the origin of their inhabitants depend on many causes, of which climate is one of chief importance, though difference of longitude as well as latitude, is generally accompanied by a dissimilarity of indigenous species.

Therefore, as different seas and lakes are inhabited, at the same period, in different zones and depths, by different aquatic animals and plants, and as the lands adjoining these may be peopled by distinct terrestrial species, it follows that distinct fossils will be embedded in contemporaneous deposits. If it were otherwise—if the same species abounded in every climate, or in every part of the globe where, so far as we can discover, a corresponding temperature and other conditions favourable to their existence are found—the identification of mineral masses of the same age, by means of their included organic contents, would be a matter of still greater certainty.

Nevertheless, the extent of some single zoological provinces, especially those of marine animals, is very great ; and our geological researches have proved that the same laws prevailed at remote periods ; for the fossils are often identical throughout wide spaces, and in detached deposits, consisting of rocks, varying entirely in their mineral nature.

The doctrine here laid down will be more readily understood, if we reflect on what is now going on in the Mediterranean. That entire sea may be considered as one zoological province ; for although certain species of testacea and zoophytes may be very local, and each region, according to its depth, the temperature and saltness of the water and other conditions, has probably some species peculiar to it, still a considerable number are common to the whole Mediterranean. If, therefore, at some future period, the bed of this inland sea should be converted into land, the geologist might be enabled, by reference to organic remains, to prove the contemporaneous origin of various mineral masses scattered over a space equal in area to half of Europe.

Deposits, for example, are well known to be now in progress in this sea in the deltas of the Po, Rhone, Nile, and other rivers, which differ as greatly from each other in the nature of their sediment as does the mineral composition of the mountains which they drain. There are also other quarters of the Mediterranean, as off the coast of Campania, or near the base of Etna, in Sicily, or in the Grecian Archipelago, where another class of rocks is now forming; where showers of volcanic ashes occasionally fall into the sea, and streams of lava overflow its bottom; and where, in the intervals between volcanic eruptions, beds of sand and clay are frequently derived from the waste of cliffs, or the turbid waters of rivers. Limestones, moreover, such as the Italian travertins, are here and there precipitated from the waters of mineral springs, some of which rise up from the bottom of the sea. In all these detached formations, so diversified in their lithological characters, the remains of the same species of shells, Corals, Crustacea, and fish are becoming enclosed; or at least, a sufficient number must be common to the different localities to enable the zoologist to refer them all to one contemporaneous assemblage of species.

There are, however, certain combinations of geographical circumstances which cause distinct provinces of animals and plants to be separated from each other by very narrow limits; and hence it must happen that strata, on the same geological horizon, will be sometimes formed in contiguous regions, differing widely both in mineral contents and organic remains. Thus, for example, the Testacea, Zoophytes, and fish of the Red Sea are, as a group, distinct from those inhabiting the adjoining parts of the Mediterranean, the narrow isthmus of Suez having acted as an efficient barrier. Calcareous formations have accumulated on a great scale in the Red Sea in modern times, and fossil shells of existing species are well preserved therein; and we know that at the mouth of the Nile, large deposits of mud are amassed, including the remains of Mediterranean species. It follows, therefore, that if at some future period the bed of the Red Sea should be laid dry, the geologist might experience great difficulties in endeavouring to ascertain the relative age of these formations, which, although dissimilar both in organic and mineral characters, were of synchronous origin.

But there are some species of Testacea common to the Mediterranean and Red Sea, and their presence would indicate to the geologist, of the remote future, a greater or less synchronism.

In some parts of the globe the line of demarcation between distinct provinces of animals and plants, is not very strongly marked, especially where the change is determined by tem-

perature, as it is in seas extending from the temperate to the tropical zone, or from the temperate to the Arctic regions. Here a gradual passage takes place from one set of species to another. In like manner, the geologist, in studying particular formations of remote periods, has sometimes been able to trace the gradation from one ancient province to another, by carefully observing the fossils of all the intermediate places. His success in thus acquiring a knowledge of the zoological or botanical geography of very distant areas, has been mainly owing to this circumstance, that the mineral character has no tendency to be affected by climate. A large river may convey yellow or red mud into some part of the ocean, where it may be dispersed by a current over an area several hundred leagues in length, so as to pass from the tropics into the temperate zone. If the bottom of the sea be afterwards upraised, the organic remains embedded in such yellow or red strata may indicate the different animals or plants which once inhabited at the same time the temperate and equatorial regions.

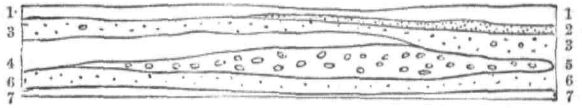
It may be true, as a general rule, that groups of the same species of animals and plants may extend over wider areas than deposits of homogeneous composition ; and if so, palæontological characters will be of more importance in geological classification than the test of mineral composition.

Test by included fragments of older rocks.—It was stated that proof may sometimes be obtained of the relative date of two formations, by fragments of an older rock being included in a newer one. This evidence may sometimes be of great use, where a geologist is at a loss to determine the relative age of two formations from want of clear sections exhibiting their true order of position, or because the strata of each group are vertical. In such cases we sometimes discover that the more modern rock has been in part derived from the degradation of the older. Thus, for example, we may find chalk in one part of a country, and in another strata of clay, sand, and pebbles. If some of these pebbles consist of that peculiar flint, of which layers more or less continuous are characteristic of the Chalk, and which include fossil shells, Sponges, and Foraminifera of Cretaceous species, we may confidently infer that the chalk was the older of the two formations.

Chronological groups.—The separate groups into which the fossiliferous strata may be divided, are more or less numerous, according to the views of classification which different geologists may entertain ; but when we have adopted a certain system of arrangement, we immediately find that a few only of the entire series of groups occur one upon the other in any single section or district.

The thinning out of individual strata was before described (p. 17). But let the annexed diagram represent seven fossili-

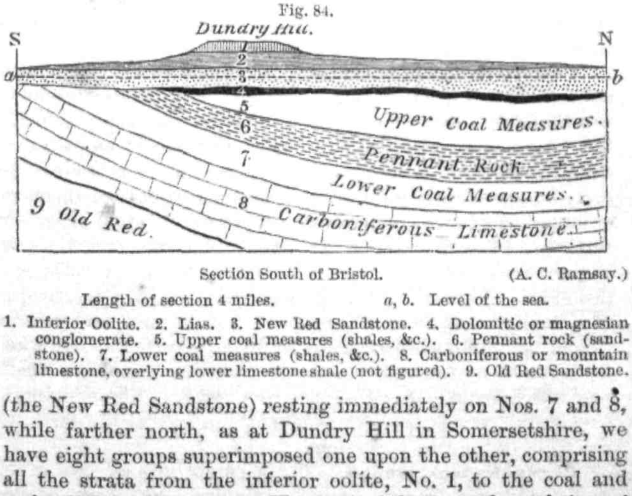
Fig. 83.



ferous groups, instead of as many strata. It will then be seen that in the middle all the superimposed formations are present; but in consequence of some of them thinning out, No. 2 and No. 5 are absent at one extremity of the section, and No. 4 at the other.

In another diagram (fig. 84) a true section of the geological formations in the neighbourhood of Bristol and the Mendip Hills is presented to the reader, as laid down on a natural scale by Sir A. Ramsay, where the newer groups 1, 2, 3, 4 rest unconformably on the formations 5, 6, 7, and 8. At the southern end of the line of section we meet with the beds No. 3

Fig. 84.



Section South of Bristol. (A. C. Ramsay.)

Length of section 4 miles. *a*, *b*. Level of the sea.

1. Inferior Oolite. 2. Lias. 3. New Red Sandstone. 4. Dolomitic or magnesian conglomerate. 5. Upper coal measures (shales, &c.). 6. Pennant rock (sandstone). 7. Lower coal measures (shales, &c.). 8. Carboniferous or mountain limestone, overlying lower limestone shale (not figured). 9. Old Red Sandstone.

(the New Red Sandstone) resting immediately on Nos. 7 and 8, while farther north, as at Dundry Hill in Somersetshire, we have eight groups superimposed one upon the other, comprising all the strata from the inferior oolite, No. 1, to the coal and carboniferous limestone. The limited horizontal extension of the groups 1 and 2 is owing to subsequent denudation, as these formations end abruptly, and have left outlying patches to attest the fact of their having originally covered a much wider area.

In order, therefore, to establish a chronological succession of

fossiliferous groups, a geologist must begin with a single section in which several sets of strata lie one upon the other. He must then trace these formations, by attention to their mineral character and fossils, continuously as far as possible, from the starting point. As often as he meets with new groups, he must ascertain their age relatively to those first examined by superposition, and thus learn how to intercalate them in a tabular arrangement of the whole.

By this means the German, French, and English geologists have determined the succession of strata throughout the greater part of Europe, and have adopted pretty generally the following groups, almost all of which have their representatives in the British Islands.

It must be understood, however, that although in a given locality there may be a physical break—unconformity—and also a palæontological break, between two successive groups of strata, these evidences of lapse of time will not be discovered universally and wherever the groups are in contact. Somewhere or other, the groups will pass insensibly one into the other and the classificatory distinctions are no longer of value.

All stratigraphical schemes are therefore more or less artificial and arbitrary, for the changes were not contemporaneous over the whole globe.

From what has been stated, it may be accepted as a general but not a perfectly strict truth, that strata of different countries which contain the same species of fossils are of similar geological age. Such strata are said to be 'equivalent,' 'on the same geological horizon,' and these terms are used in a very wide sense. But the strata containing the same species of fossils, may be widely separated, geographically, and this fact is opposed to the idea of exact contemporaneity, for it took time for the species to disperse.

*ABRIDGED GENERAL TABLE OF FOSSILIFEROUS STRATA.

Strata		Formation	Group	Division
1. RECENT.		POST-TERTIARY.	TERTIARY or CAINOZOIC.	NEOZOIC.
2. PLEISTOCENE.		POST-TERTIARY.	TERTIARY or CAINOZOIC.	NEOZOIC.
3. NEWER PLIOCENE.		PLIOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
4. OLDER PLIOCENE.		PLIOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
5. MIOCENE.		MIOCENE and OLIGOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
6. OLIGOCENE.		MIOCENE and OLIGOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
7. UPPER EOCENE.		EOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
8. MIDDLE EOCENE.		EOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
9. LOWER EOCENE.		EOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
10. MAESTRICHT BEDS.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
11. WHITE CHALK.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
12. CHLORITIC SERIES.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
13. GAULT.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
14. NEOCOMIAN.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
15. WEALDEN.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
16. PURBECK BEDS.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
17. PORTLAND STONE.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
18. KIMMERIDGE CLAY.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
19. CORAL RAG.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
20. OXFORD CLAY.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
21. GREAT or BATH OOLITE.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
22. INFERIOR OOLITE.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
23. LIAS.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
24. UPPER TRIAS AND RHÆTIC.		TRIASSIC.	SECONDARY or MESOZOIC.	
25. MIDDLE TRIAS.		TRIASSIC.	SECONDARY or MESOZOIC.	
26. LOWER TRIAS.		TRIASSIC.	SECONDARY or MESOZOIC.	
27. PERMIAN.		PERMIAN.	PRIMARY or PALÆOZOIC.	
28. COAL-MEASURES AND GRITS.		CARBONIFEROUS.	PRIMARY or PALÆOZOIC.	
29. CARBONIFEROUS LIMESTONE AND SHALES.		CARBONIFEROUS.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
30. UPPER	DEVONIAN.	DEVONIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
31. MIDDLE	DEVONIAN.	DEVONIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
32. LOWER	DEVONIAN.	DEVONIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
33. UPPER	SILURIAN.	SILURIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
34. LOWER	SILURIAN.	SILURIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
35. UPPER	CAMBRIAN.	CAMBRIAN.	PRIMARY or PALÆOZOIC.	
36. LOWER	CAMBRIAN.	CAMBRIAN.	PRIMARY or PALÆOZOIC.	
37. UPPER	PRE-CAMBRIAN. LAURENTIAN.	LAURENTIAN on ARCHÆAN.	PRIMARY or PALÆOZOIC.	
38. LOWER	PRE-CAMBRIAN. LAURENTIAN.	LAURENTIAN on ARCHÆAN.	PRIMARY or PALÆOZOIC.	

TABULAR VIEW

OF

THE FOSSILIFEROUS STRATA.

SHOWING THE ORDER OF SUPERPOSITION OR CHRONOLOGICAL SUCCESSION OF THE PRINCIPAL GROUPS, WITH REFERENCE TO THE PAGES WHERE THEY ARE DESCRIBED IN THIS WORK.

POST-TERTIARY.

		EXAMPLES.
POST-TERTIARY	1 **RECENT** Shells and mammalia, all of living species.	*British*—Clyde marine strata, with canoes (p. 116). *Foreign*—Danish Kitchen-middens (p. 116). Lacustrine mud, with remains of Swiss lake-dwellings (p. 117).
	2 **PLEISTOCENE** Shells recent, mammalia in part extinct.	*British*—Loam of Brixham cave, with flint implements and bones of extinct and living quadrupeds (p. 127). Drift near Salisbury, with bones of mammoth, Spermophilus, and stone implements (p. 130). Glacial drift of Scotland, with marine shells and remains of mammoth (p. 144). Erratics of Chichester (p. 152). Glacial drift of Wales, with marine fossil shells about 1,400 feet high, on Moel Tryfaen (p. 148). Bridlington beds, marine Arctic fauna (p. 152). Glacial boulder formation of Norfolk cliffs (p. 150). Chillesford and Aldeby beds, with marine shells, chiefly Arctic (p. 151). *Foreign*—Dordogne caves of the reindeer period (p. 119). Older Valley gravels of Amiens, with flint implements and bones of extinct mammalia (p. 122). Loess of Rhine (p. 125). Loam and breccia of Liége caverns, with human remains (p. 126). Australian cave breccias, with bones of extinct marsupials (p. 128). Glacial drift of Northern Europe (p. 152).

TERTIARY OR CAINOZOIC.

PLIOCENE	3 **NEWER PLIOCENE** The shells almost all of living species.	*British*—Forest-bed of Norfolk cliffs, with bones of *Elephas meridionalis*, &c. (p. 158). Norwich crag (p. 159). *Foreign*—Eastern base of Mount Etna, with marine shells (p. 170). Sicilian strata (p. 169). Lacustrine strata of Upper Val d'Arno (p. 171). German and French pliocene (pp. 173–175).
	4 **OLDER PLIOCENE** Extinct species of shells forming a large minority.	*British*—Red crag of Suffolk, marine shells, some of northern forms (p. 160). White or coralline crag of Suffolk (p. 163). *Foreign*—Diestien and Antwerp crag (p. 168). Subapennine marls and sands (p. 171). Pliocene of North America (p. 176). Deposit at Pikermi, near Athens (p. 175). Strata of the Siwâlik hills, India (p. 176).

		EXAMPLES.
MIOCENE	5 **MIOCENE** *Majority of the shells extinct.*	*British*—Wanting. *Foreign*—Faluns of Touraine (p. 179). Faluns, proper, of Bordeaux (p. 181). Freshwater strata of Gers (p. 182). Swiss Œningen beds, rich in plants and insects (pp. 183–191). Marine molasse, Switzerland (p. 191). Vienna basin (p. 192). Mayence basin (p. 193). Beds of the Superga, near Turin (p. 193). Miocene of the Western territories, United States (p. 193). Marine miocene of India, Egypt, and West Indies (p. 194). Australia.
OLIGO-CENE	6 **OLIGO-CENE**	*British*—Hempstead beds, Bembridge fluvio-marine series, Osborne series (pp. 208–211). Headon series (p. 211). *Foreign*—*French*—Calcaire de la Beauce (p. 196). Grès de Fontainebleau (p. 196). Sables d'Etampes (p. 196). Lacustrine gypseous series of Montmartre (p. 196). Auvergne, the Limagne (p. 200). *Belgian*—Rupelian and Tongrian (p. 201). *Switzerland*—Aquitanian and lower molasse strata (p. 203). *Germany*—Brown coal of Lower Rhine (p. 207). Septarien-Thon, marine beds of Egeln (p. 207). *Austria*—Vienna basin deposits, with *Cerithium plicatum* (p. 215). Croatian brown coal (p. 214). India, Nari series (p. 215).
EOCENE	7 **UPPER**	*British*—Upper Bagshot and Barton clay (p. 217). *Foreign*—*French*—Marine gypseous series (p. 232). Calcaire de St. Ouen (p. 232). Grès de Beauchamp (p. 232). *Belgian*—Wemmelian (p. 236). *American*—Uinta group (p. 240).
	8 **MIDDLE**	*British*—Middle Bagshot, Bracklesham beds (pp. 218–221). Bovey Tracey and Mull leaf-beds (p. 222). Arctic leaf-beds (p. 224). *Foreign*—*French*—Calcaire grossier (p. 232). *Belgian*—Laekenian and Bruxellian (p. 236). *American*—Bridger group (p. 240). Nummulitic limestone of Europe and Asia and Africa (p. 235).
	9 **LOWER**	*British*—London clay, Oldhaven beds (pp. 226–229). Woolwich and Reading series, Thanet sands (pp. 229–231). *Foreign*—*French*—Sables de Cuise (p. 233). Argile plastique (p. 234). Sables de Bracheux (p. 234). Cong. de Mendon et Rilly (pp. 234, 235). *Belgian*—Paniselian, Ypresian, Landenian, Heersian, and Calcaire grossier de Mons (pp. 235, 236). *North America*—Zeuglodon beds of East (p. 238). Wahsatch group of West (p. 240).

SECONDARY OR MESOZOIC.

CRETACE-OUS	10 **UPPER CRETACE-OUS**	*British*—Upper white chalk, with flints (p. 247). Lower white chalk, without flints (p. 258). Chalk marl (p. 259). Chloritic series (or Upper Greensand), fire-stone of Surrey (p. 260). Blackdown beds (p. 260). Gault (p. 261).

		EXAMPLES.
CRETACEOUS	10 UPPER CRETACEOUS	*Foreign*—Maestricht beds and Faxoe chalk (pp. 243–246). Pisolitic limestone of France (p. 245). White chalk of France, Sweden, and Russia (p. 264). Quader sandstone and Pläner-Kalk of Saxony (p. 252). Sands and clays of Aix-la-Chapelle (p. 262). Hippurite limestone of South of France (p. 264). New Jersey, U.S., sands and marls (p. 266). Western series (p. 267).
	11 LOWER CRETACEOUS or NEOCOMIAN	*British*—Sands of Folkestone, Sandgate, Hythe, and the Isle of Wight (p. 269). Atherfield clay, with *Perna mulleti* (p. 270). Speeton clay of Yorkshire, and Tealby sands and sandstones of Lincolnshire (pp. 272, 273). Punfield marine beds, with *Vicarya lujana* (p. 279). Weald clay of Surrey, Kent, and Sussex, freshwater, with *Cypris* (p. 275). Hastings sands (p. 277). *Foreign*—Neocomian of Neufchâtel, and Hils conglomerate of North Germany (p. 273). Wealden beds of Hanover (p. 280). Tithonian (p. 281).
OOLITE	12 UPPER OOLITE	*British*—Upper Purbeck beds, freshwater (p. 284). Middle Purbeck, with numerous marsupial quadrupeds, &c. (p. 285). Lower Purbeck, freshwater, with intercalated dirt-bed (p. 290). Portland stone and sand (p. 293). Kimmeridge clay (p. 295). *Foreign*—Marines à *Gryphæa virgula* of Argonne (p. 295). Lithographic stone of Solenhofen, with *Archæopteryx* (p. 296).
	13 MIDDLE OOLITE	*British*—Coral rag of Berkshire, Wilts, and Yorkshire (p. 298). Oxford clay, with belemnites and ammonites (p. 299). Kelloway rock of Wilts and Yorkshire (p. 300). *Foreign*—Nerinæan limestone of the Jura (p. 299).
	14 LOWER OOLITE	*British*—Cornbrash and forest marble (p. 300). Great or Bath oolite (p. 301). Stonesfield slate, with marsupials (p. 304). Fuller's earth of Bath (p. 308). Inferior oolite (p. 308).
LIAS	15 LIAS	Upper lias, argillaceous, with *Ammonites striatulus* (p. 312). Shale and limestone, with *Ammonites bifrons* (p. 315). Middle lias or Marlstone series, with zones containing characteristic ammonites (p. 312). Lower lias, also with zones characterised by peculiar ammonites, Infra lias series (pp. 312–316).
…AS	16 UPPER TRIAS	*British*—Rhætic, Penarth or *Avicula contorta* beds (beds of passage), (p. 325). Keuper or Upper New Red sandstone, &c. (p. 328). Red shales of Cheshire and Lancashire, with rock-salt (p. 333). Dolomitic conglomerate of Bristol (p. 331). *Foreign*—Rhætic (p. 327). Keuper beds of Germany (p. 335, 336). St. Cassian or Hallstadt beds, with rich marine fauna (p. 337). Coalfield of Richmond, Virginia (p. 341). Chatham coalfield, North Carolina (p. 342).
	17 MIDDLE TRIAS	*British*—Wanting. *Foreign*—Muschelkalk of Germany (p. 338).
	18 LOWER TRIAS	*British*—Bunter or Lower New Red sandstone of Lancashire and Cheshire (p. 332). *Foreign*—Bunter-Sandstein of Germany (p. 340). Red sandstone of Connecticut Valley (p. 341). India (p. 341).

PRIMARY OR PALÆOZOIC.

		Examples.
PERMIAN	19 PERMIAN	*British*—Upper Permian of St. Bees' Head and Corby, Cumberland (p. 345). Middle Permian, magnesian limestone, and marl-slate of Durham and Yorkshire, with *Protorosaurus* (p. 345). Lower Permian sandstones and breccias of Penrith and Dumfriesshire (p. 349). *Foreign*—Dark-coloured shales of Thuringia (p. 350). Zechstein or Dolomitic limestone (p. 350). Mergel-Schiefer or Kupfer-Schiefer (p. 350). Roth-liegendes of Thuringia, with *Psaronius* (p. 350). Magnesian limestones, &c., of Russia (p. 351).
CARBONIFEROUS	20 UPPER CARBONIFEROUS	*British*—Coal measures of South Wales, with underclays enclosing *Stigmaria* (p. 354). Coal measures of North and Central England (p. 354). Millstone grit (p. 355). Yoredale series of Yorkshire (p. 355). Coalfield of Kilkenny, with *Labyrinthodont* (p. 383). *Foreign*—Coalfield of Saarbrück, with *Archegosaurus* (p. 383). Carboniferous strata of South Joggins, Nova Scotia (p. 361). Pennsylvanian coalfield (p. 380).
	21 LOWER CARBONIFEROUS	*British*—Mountain limestone of South Wales and North and Central England (p. 356). Same in Ireland and carboniferous slate (p. 357). Carboniferous limestone of Scotland alternating with coal-bearing sandstones (p. 356). Calciferous series. *Foreign*—Mountain limestone of Belgium (p. 398).
DEVONIAN or OLD RED SANDSTONE	22 UPPER DEVONIAN	*British*—Yellow sandstone of Dura Den and of Farlow, with *Holoptychius*, &c. (p. 401); and of Ireland, with *Anodon Jukesii* (p. 409). Pilton group of North Devon (p. 411). Petherwyn group of Cornwall, with *Clymenia* and *Cypridina* (p. 412). *Foreign*—Clymenien-Kalk and Cypridinen-Schiefer of Germany (p. 413).
	23 MIDDLE DEVONIAN	*British*—Ilfracombe beds with peculiar trilobites and corals (pp. 411–413). Limestones of Torquay, with numerous corals, *Clymeniæ* and *Calceolæ* (p. 413). *Foreign*—Eifel limestone, with underlying schists containing *Calceola* (p. 415). Devonian strata of Russia (p. 416).
	24 LOWER DEVONIAN	*British*—Flagstones of Forfarshire and Perth, with *Cephalaspis*, *Pterygotus*, and *Holoptychius* (p. 403). Bituminous schists of Gamrie, Caithness, &c., with numerous fish (p. 403). Sandstones and cornstones of Herefordshire, with *Pteraspis* (p. 408). Sandstones and slates of the Foreland and Linton (p. 416). *Foreign*—Sandstones of Gaspé, with *Cephalaspis* (p. 417).

		EXAMPLES.
SILURIAN	25 UPPER SILURIAN	*British*—Upper Ludlow formation, Tilestones, Downton sandstone, with bone-bed (p. 422). Lower Ludlow formation, with oldest known fish remains (p. 425). Wenlock limestone and shale (p. 427). Woolhope limestone and grit (p. 430). Tarannon shales (p. 431). Denbigh grits. Upper Llandovery or May-hill sandstone, with *Pentamerus oblongus*, &c. (p. 431). Lower Llandovery slates, *Stricklandinia lens* (p. 433).[1] *Foreign*—Oriskany, Lower Halderberg, Salina, Niagara groups (p. 444). Silurian strata of Scandinavia and Russia, with *Pentamerus* (p. 443).
	26 LOWER SILURIAN	*British*—Bala and Caradoc beds (p. 434). Llandeilo flags (p. 438). Arenig or Stiper-stones group (Lower Llandeilo of Murchison), (p. 440). *Foreign*—Obolus grit of Russia (p. 444). Trenton limestone, and other Lower Silurian groups of North America (p. 445). *Trinucleus* shales and *Cystoidean* limestone of Sweden (p. 443). (Series D.) of Bohemia (p. 444).
CAMBRIAN	27 UPPER CAMBRIAN	*British*—Tremadoc slates (p. 447). Lingula flags, with *Lingulella Davisii* (p. 448). *Foreign*—Barrande's 'Primordial' zone of Bohemia, in part, with Trilobites of the genera *Paradoxides* (p. 454), D. *Olenus* beds and *Ceratopyge* limestone and alum schists of Sweden and Norway (p. 455). Potsdam sandstone, with *Dikelocephalus* and *Obolella* (p. 456).
	28 LOWER CAMBRIAN	*British*—Menevian beds of Wales, with *Paradoxides Davidis*, &c. (p. 450). Longmynd group, comprising the Harlech grits and Llanberis slates, and purple and green fossiliferous rocks of St. David's (p. 451). *Foreign*—Part of Barrande's 'Primordial' zone in Bohemia (p. 454), C, and part B. *Paradoxides* beds and fucoidal sandstones of Sweden (p. 456). Huronian series of Canada ? (p. 458).
ARCHÆAN	29 UPPER LAURENTIAN	*British*—Fundamental pre-Cambrian gneiss of the Hebrides ? (p. 460). Pre-Cambrian rocks of Malverns, of Caernarvonshire, Anglesea, and of Pembrokeshire (pp. 457, 458). *Foreign*—Labrador series north of the river St. Lawrence in Canada (p. 459). Adirondack mountains of New York (p. 459).
	30 LOWER LAURENTIAN	*British*—Wanting ? *Foreign*—Beds of gneiss and quartzite, with interstratified limestones, in one of which, 1,000 feet thick, occurs a foraminifer, *Eozoon Canadense*, the oldest known fossil, Canada (p. 459).

[1] Sedgwick placed the Cambrian formation just below the Llandovery strata, and thus the Lower Silurian and Upper and Lower Cambrian series all come within his Cambrian.

CHAPTER IX.

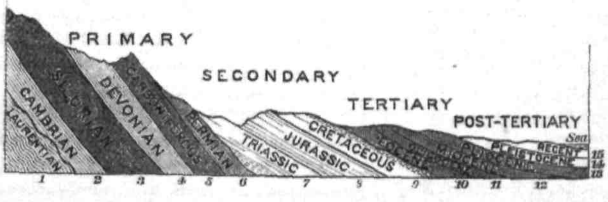
CLASSIFICATION OF TERTIARY FORMATIONS.

Order of succession of sedimentary formations—Frequent unconformability of strata—Imperfection of the record—Defectiveness of the monuments greater in proportion to their antiquity—Reasons for studying the newer groups first—Nomenclature of formations—Detached Tertiary formations scattered over Europe—Value of the shell-bearing mollusca in classification—Classification of Tertiary strata—Eocene, Oligocene, Miocene, and Pliocene. Terms explained.

By reference to the tables given at the end of Chapter VIII., the reader will see that when the fossiliferous rocks are arranged chronologically, we have first to consider the Post-tertiary and then the Tertiary or Cainozoic formations, and afterwards to pass on to those of older date.

Order of superposition.—The annexed diagram will show the order of superposition of these deposits, assuming them all to be visible in one continuous section. In nature we have

Fig. 85.



never an opportunity of seeing the whole of the strata displayed in a single region ; first, because sedimentary deposition is confined, during any one geological period, to limited areas ; and secondly, because strata, after they have been formed, are liable to be utterly annihilated over wide areas by denudation. But wherever certain members of the series are present, they overlie one another in the *order* indicated in the diagram, though not always in the exact manner there represented, because some of them repose occasionally in unconformable stratification on others. This mode of superposition has been already explained at p. 68, fig. 78, where I pointed out that the discord-

ance which implies a considerable lapse of time between two formations in juxtaposition is almost invariably accompanied by a great dissimilarity in the species of organic remains.

Frequent unconformability of strata.—Where the widest gaps appear in the sequence of the fossil forms, as between the Permian and Triassic rocks, or between the Cretaceous and Eocene, examples of such unconformability are very frequent. But they are also met with in some part or other of the world at the junction of almost all the other principal formations, and sometimes the subordinate divisions of any one of the leading groups may be found lying unconformably on another subordinate member of the same. Instances of such irregularities in the mode of succession of the strata, are the more intelligible the more we extend our survey of the fossiliferous formations, for we are continually bringing to light deposits of intermediate date, which have to be intercalated between those previously known, and which reveal to us a long series of events, of which, antecedently to such discoveries, we had no knowledge.

But while unconformability invariably bears testimony to a lapse of unrepresented time, the conformability of two sets of strata in contact by no means implies that the newer formation immediately succeeded the older one. It simply implies that the ancient rocks were subjected to no movements of such a nature as to tilt, bend, or break them before the more modern formation was superimposed. It does not show that the earth's crust was motionless in the region in question, for there may have been a gradual sinking or rising, extending uniformly over a large surface, and yet during such movement the stratified rocks may have retained their original horizontality of position. Strata possessing very different animal remains and different kinds of rocks may still be conformable, yet great changes must have occurred. There may have been a conversion of a wide area from sea into land and from land into sea, and during these changes of level some strata may have been slowly removed by aqueous action, and after this new strata may be superimposed, differing perhaps in date by thousands of years or centuries, and yet resting conformably on the older set. There may even be a blending of the materials constituting the older deposit with those of the newer, so as to give rise to a passage in the mineral character of the one rock into the other as if there had been no break or interruption in the depositing process.

Imperfection of the record.—Although by the frequent discovery of new sets of intermediate strata, the transition from one type of organic remains to another is becoming less and less abrupt, yet the entire series of records appears to the geologists

now living far more fragmentary and defective than it seemed to their predecessors half a century ago. The earlier inquirers, as often as they encountered a break in the regular sequence of formations, connected it, theoretically, with a sudden and violent catastrophe, which had put an end to the regular course of events that had been going on uninterruptedly for ages, annihilating at the same time all or nearly all the organic beings which had previously flourished, after which, order being re-established, a new series of events was initiated. In proportion as our faith in these views grows weaker, and the phenomena of the organic or inorganic world presented to us by geology seem explicable on the hypothesis of gradual and insensible changes, varied only by occasional convulsions, on a scale comparable to that witnessed in historical times ; and in proportion as it is thought possible that former fluctuations in the organic world may be due to the indefinite modifiability of species without the necessity of assuming new and independent acts of creation, the number and magnitude of the gaps which still remain, or the extreme imperfection of the record, become more and more striking, and what we possess of the ancient annals of the earth's history appears as nothing when contrasted with that which has been lost.

It is observed that strata, in proportion as they are of newer date, bear the nearest resemblance in mineral character to those which are now in the progress of formation in seas or lakes, the newest of all consisting principally of soft mud or loose sand, in some places full of shells, corals, or other organic bodies, animal or vegetable, in others wholly devoid of such remains. The farther we recede from the present time, and the higher the antiquity of the formations which we examine, the greater are the changes which the sedimentary deposits have undergone. Time, as I have explained in Chapters V., VI., and VII., has multiplied the effects of condensation by pressure and cementation, and the modification produced by heat, fracture, contortion, upheaval, and denudation. The organic remains also have sometimes been obliterated entirely, or the mineral matter of which they were composed has been removed and replaced by other substances.

Why newer groups should be studied first.—We likewise observe that the older the rocks the more widely do their organic remains depart from the types of the living creation. First, we find in the newer tertiary rocks a few species which no longer exist, mixed with many living ones, and then, as we go farther back, many genera and families at present unknown make their appearance, until we come to strata in which the fossil relics of existing species are nowhere to be detected, except

a few of the lowest forms of invertebrata, while some orders of animals and plants, wholly unrepresented in the living world, begin to be conspicuous.

When we study, therefore, the geological records of the earth and its inhabitants, we find, as in human history, the defectiveness and obscurity of the monuments always increasing the remoter the era to which we refer, the rocks becoming more generally altered and crystalline the older they are, and the difficulty of determining their true chronological relations becoming more and more enhanced, especially when we are comparing those which were formed in very distant regions of the globe. Hence we advance with securer steps when we begin with the study of the geological records of later times, proceeding from the newer to the older, or from the more to the less known.

In thus inverting what might at first seem to be the more natural order of historical research, we must bear in mind that each of the periods above enumerated, even the shortest, such as the Post-tertiary, or the Pliocene, Miocene, or Eocene, embrace a succession of events of vast extent, so that to give a satisfactory account of what we already know of any one of them would require many volumes. When, therefore, we study one of the newer groups before endeavouring to decipher the monuments of an older one, it is like endeavouring to master the history of our own country and that of some contemporary nations, before we enter upon Roman History ; or like investigating the annals of Ancient Italy and Greece before we approach those of Egypt and Assyria.

Nomenclature.—The origin of the terms Primary and Secondary, and the synonymous terms Palæozoic and Mesozoic, have been explained in the Eighth Chapter, p. 92.

The Tertiary or Cainozoic strata (see p. 102) were so called because they were all posterior in date to the Secondary series, of which last the Chalk or Cretaceous constitutes the newest group. The whole of the Tertiaries were at first confounded with the superficial alluviums of Europe ; and it was long before their real extent and thickness, and the various ages to which they belong, were fully recognised. They were observed to occur in patches, some of freshwater, others of marine origin, their geographical area being usually small as compared to the secondary formations, and their position often suggesting the idea of their having been deposited in different bays, lakes, estuaries, or inland seas, after a large portion of the space now occupied by Europe had already been converted into dry land.

The first deposits of this class of which the characters were

accurately determined, were those occurring in the neighbourhood of Paris, described in 1810 by MM. Cuvier and Brongniart. They were ascertained to consist of successive sets of strata, some of marine, others of freshwater origin, lying one upon the other. The fossil shells and corals were perceived to be almost all of unknown species, and to have in general a near affinity to those now inhabiting warmer seas. The bones and skeletons of land animals, some of them of large size, and belonging to more than forty distinct species, were examined by Cuvier, and declared by him not to agree specifically, nor most of them even generically, with any hitherto observed in the living creation.

Strata were soon afterwards brought to light in the vicinity of London, and in Hampshire, which, although dissimilar in mineral composition, were justly inferred by Mr. T. Webster to be of the same age as those of Paris, because the greater number of the fossil shells were specifically identical. For the same reason, rocks found in the Gironde, in the South of France, and at certain points in the North of Italy, were suspected to be of contemporaneous origin.

Another important discovery was soon afterwards made by Brocchi in Italy, who investigated the argillaceous and sandy deposits replete with shells, which form a low range of hills flanking the Apennines on both sides, from the plains of the Po to Calabria. These lower hills were called by him the Subapennines, and were formed of strata chiefly marine, and newer than those of Paris and London.

Another tertiary group occurring in the neighbourhood of Bordeaux and Dax, in the South of France, was examined by M. de Basterot in 1825, who described and figured several hundred species of shells, which differed for the most part both from the Parisian series and those of the Subapennine hills. It was soon, therefore, suspected that this fauna might belong to a period intermediate between that of the Parisian and Subapennine strata, and it was not long before the evidence of superposition was brought to bear in support of this opinion; for other strata contemporaneous with those of Bordeaux were observed in one district (the Valley of the Loire) to overlie the Parisian formation, and in another (in Piedmont) to underlie the Subapennine beds. The first example of these was pointed out in 1829 by M. Desnoyers, who ascertained that the sand and marl of marine origin called Faluns, near Tours, in the basin of the Loire, full of seashells and corals, rested upon a lacustrine formation, which constitutes the uppermost subdivision of the Parisian group, extending continuously throughout a great table-land intervening between the basin of the Seine

and that of the Loire. The other example occurs in Italy, where strata, containing many fossils similar to those of Bordeaux, were observed by Bonelli and others in the environs of Turin, subjacent to strata belonging to the Subapennine group of Brocchi. Long afterwards the superficial layers which cover many of these, and which have their stones scratched and polished, were found to contain arctic shells.

Value of testacean fossils in classification.—It will be observed that in the foregoing allusions to organic remains, the testacea or the shell-bearing mollusca, are selected as the most useful and convenient class for the purposes of general classification. In the first place, they are more universally distributed through strata of every age than any other organic bodies. Those families of fossils which are of rare and casual occurrence are absolutely of no avail in establishing a chronological arrangement. If we have plants alone in one group of strata and the bones of mammalia in another, we can draw no conclusion respecting the affinity or discordance of the organic beings of the two epochs compared; and the same may be said if we have plants and vertebrated animals in one series and only shells in another. Although corals are more abundant, in a fossil state, than plants, reptiles, or fish, they are still rare when contrasted with shells, because they are more dependent for their well-being on the constant clearness of the water, and are, therefore, less likely to be included in rocks which endure in consequence of their thickness and the copiousness of sediment which prevailed when they originated. The utility of the Testacea is, moreover, enhanced by the circumstance that some forms are proper to the sea, others to the land, and others to fresh water. Rivers scarcely ever fail to carry down into their deltas some land-shells, together with species which are at once fluviatile and lacustrine. By this means we learn what terrestrial, freshwater, and marine species coexisted at particular eras of the past; and having thus identified strata formed in seas with others which originated contemporaneously in inland lakes, we are then enabled to advance a step farther, and show that certain quadrupeds or aquatic plants, found fossil in lacustrine formations, inhabited the globe at the same period when certain fish, reptiles, and zoophytes lived in the ocean.

Among other characters of the molluscous animals, which render them extremely valuable in settling chronological questions in geology, may be mentioned, first, the wide geographical range of many species; and, secondly, what is probably a consequence of the former, the great duration in time of species in this class, for they appear to have surpassed in longevity the

greater number of the fish and mammalia. Had each species inhabited a very limited space, it could never, when imbedded in strata, have enabled the geologist to identify deposits at distant points over large areas ; or had they each lasted but for a brief period, they could have thrown no light on the connection of rocks placed far from each other in the chronological, or, as it is often termed, vertical series.

Classification of Tertiary strata.—Many authors have divided the European Tertiary strata into three groups—lower, middle, and upper ; the lower comprising the oldest formations of Paris and London before mentioned ; the middle those of Bordeaux and Touraine in France, and mostly wanting in England ; and the upper all those newer than the middle group, comprising in England the crags of Norfolk and Suffolk.

In the first edition of the 'Principles of Geology' I divided the whole of the Tertiary formations into four groups, characterised by the percentage of recent shells which they contained. The lower tertiary strata of London and Paris were thought by M. Deshayes to contain only $3\frac{1}{2}$ per cent. of recent species, and were termed Eocene. The middle tertiary of the Loire and Gironde had, according to the specific determinations of the same eminent conchologist, 17 per cent., and formed the Miocene division. The Subapennine beds contained 35 to 50 per cent., and were termed Older Pliocene, while still more recent beds in Sicily, which had from 90 to 95 per cent. of species identical with those now living, were called Newer Pliocene. The first of the above terms, Eocene, is derived from ηως, eos, *dawn*, and καινος, cainos, *recent*, because the fossil shells of this period contain an extremely small proportion of living species, which may be looked upon as indicating the dawn of the existing state of the testaceous fauna, no recent species (with one or two exceptions) having been detected in the older or secondary rocks.

The term Miocene (from μειον, meion, *less*, and καινος, cainos, *recent*), is intended to express a minor proportion of recent species (of testacea), the term Pliocene (from πλειον, pleion, *more*, and καινος, cainos, *recent*), a comparative plurality of the same. It may assist the memory of students to remind them, that the *Mi*ocene contain a *mi*nor proportion, and *Pl*iocene, a comparative *pl*urality of recent species ; and that the greater number of recent species always implies the more modern origin of the strata.

Subsequently to this classification, Beyrich founded the 'Oligocene' as a division intermediate between the Eocene proper and the Miocene. This division includes the Lower Miocene formations of the previous editions of this work, and much

of the Upper Eocene series. Nummulites became scarce and degenerated in the Oligocene series, which in Europe contains very important freshwater beds with mammalian remains and also many marine tracts.

Since the year 1830 the number of known shells, both recent and fossil, has largely increased, and their identification has been more accurately determined. Hence some modifications have been required in the classifications founded on less perfect materials. The Eocene, Oligocene, Miocene, and Pliocene periods have been made to comprehend certain sets of strata of which the fossils do not always conform strictly in the numerical proportion of recent to extinct species with the definitions first given by me, or which are employed in the etymology of those terms.

CHAPTER X.

RECENT AND PLEISTOCENE PERIODS.

Recent and Pleistocene periods—Terms defined—Formations of the recent Period—Modern littoral deposits containing works of art near Naples—Danish peat and shell mounds—Swiss lake-dwellings—Periods of stone, bronze, and iron—Pleistocene formations—Coexistence of man with extinct mammalia—Reindeer period of South of France—Alluvial deposit of Palæolithic age—Higher and Lower-level Valley gravels—Loess or inundation mud of the Nile, Rhine, &c.—Origin of caverns—Remains of man and extinct quadrupeds in cavern deposits—Cave of Kirkdale—Australian cave-breccias—Geographical relationship of the provinces of living vertebrata and those of extinct Pleistocene species—Extinct struthious birds of New Zealand—Climate of the Pleistocene period—Comparative longevity of species in the mammalia and testacea—Teeth of Recent and Pleistocene mammalia.

We have seen in the last chapter that the uppermost or newest strata are called Post-tertiary, as being more modern than the Tertiary. The term Quaternary has often been applied to them. The Post-tertiary formations are divided into two subordinate groups: the Recent and the Pleistocene. In the Recent period, all the mammalia as well as the shells are identical with species now living; whereas in the Pleistocene, the shells being all of living forms, a part, and often a considerable part, of the mammalia belong to extinct species. In former editions of this work I divided the Post-tertiary deposits into Recent and Post-pliocene, but this latter term has many inconveniences, especially that of often being confounded with Post-tertiary. I have, therefore, determined for the future to adopt the name of

'Pleistocene,' proposed by me in 1839 as a synonym for Newer Pliocene, but which, having been used by the late Edward Forbes as the equivalent of Post-pliocene, has now passed into general use with that signification. In this volume the term 'Pleistocene' will accordingly be used for the older subdivision of the Post-tertiary, and I shall only sometimes retain, in a parenthesis, the word Post-pliocene, to remind the reader that Pleistocene is used as its synonym.

Cases will occur where it may be scarcely possible to draw the boundary line between the Recent and Pleistocene (Post-pliocene) deposits; and we must expect these difficulties to increase rather than diminish with every advance in our knowledge, and in proportion as gaps are filled up in the series of records.

RECENT PERIOD.

It was stated in the sixth chapter, when I treated of denudation, that the dry land, or that part of the earth's surface which is not covered by the waters of lakes or seas, is generally wasting away by the incessant action of rain and rivers, and in some cases by the undermining and removing power of waves and tides on the sea-coast. But the rate of waste is very unequal, since the level and gently sloping lands, where they are protected by a continuous covering of vegetation, escape nearly all wear and tear, so that they may remain for ages in a stationary condition, while the removal of matter is constantly widening and deepening the intervening ravines and valleys.

The materials, both fine and coarse, carried down annually by rivers from the higher regions to the lower, and deposited in successive strata in the basins of seas and lakes, must be of enormous volume. We are always liable to underrate their magnitude, because the accumulation of strata is going on out of sight.

There are, however, causes at work which, in the course of centuries, tend to render visible these modern formations, whether of marine or lacustrine origin. For a large portion of the earth's crust is always undergoing a change of level, some areas rising and others sinking at the rate of a few inches, or a few feet, perhaps sometimes yards, in a century, so that spaces which were once subaqueous are gradually converted into land, and others which were high and dry become submerged. In some districts on the borders of the sea, at very different elevations above its level, raised beaches occur; in others there are marine littoral deposits, such as those in which, on the borders of the Bay of Baiæ, near Naples, the well-known temple of

Serapis was embedded. In that case the date of the monument buried in the marine strata is ascertainable, but in many other, and more or less similar, instances the exact age of the remains of human workmanship is uncertain, as in the estuary of the Clyde at Glasgow, where many canoes have been exhumed, with other works of art, all assignable to some part of the Recent Period.

Danish peat and shell mounds or kitchen-middens.—Sometimes we obtain evidence, without the aid of a change of level, of events which took place in prehistoric times. The combined labours, for example, of the antiquary, zoologist, and botanist have brought to light many monuments of the early inhabitants buried in peat mosses in Denmark. Their geological age is determined by the fact that, not only the contemporaneous freshwater and land shells, but all the quadrupeds, found in the peat, agree specifically with those now inhabiting the same districts, or which are known to have been indigenous in Denmark within the memory of man. In the lower beds of peat (a deposit varying from 20 to 30 feet in thickness), weapons of stone accompany trunks of the Scotch fir, *Pinus sylvestris.* This peat may be referred to that part of the stone period for which Sir John Lubbock proposed the name of 'Neolithic,'[1] in contradistinction to a still older era, termed by him 'Palæolithic,' and which will be described in the sequel. In the higher portions of the same Danish bogs, bronze implements are associated with trunks and acorns of the common oak. It appears that the pine has never been a native of Denmark in historical times, and it seems to have given place to the oak about the time when articles and instruments of bronze superseded those of stone. It also appears that, at a still later period, the oak itself became scarce, and was nearly supplanted by the beech, a tree which now flourishes luxuriantly in Denmark. Again, at the still later epoch when the beech-tree abounded, tools of iron were introduced, and were gradually substituted for those of bronze.

On the coasts of the Danish islands in the Baltic, certain mounds, called in those countries 'Kjökken-mödding,' or 'kitchen-middens,' occur, consisting chiefly of the castaway shells of the oyster, cockle, periwinkle, and other eatable kinds of mollusks. The mounds are from 3 to 10 feet high, and from 100 to 1,000 feet in their longest diameter. They greatly resemble heaps of shells formed by the Red Indians of North America along the eastern shores of the United States, which I saw in 1845, and have described elsewhere.[2] In the old refuse-

[1] Sir John Lubbock, Prehistoric Times, p. 3, 1865.

[2] Second Visit to United States, vol. i. p. 338. 1845.

heaps, recently studied by the Danish antiquaries and naturalists with great skill and diligence, no implements of metal have ever been detected. All the knives, hatchets, and other tools are of stone, horn, bone, or wood. With them are often intermixed fragments of rude pottery, charcoal and cinders, and the bones of quadrupeds on which the rude people fed. These bones belong to wild species still living in Europe, though some of them, like the beaver, have long been extirpated in Denmark. The *only* animal which they seem to have domesticated was the dog.

As there is an entire absence of metallic tools, these refuse-heaps are referred to the Neolithic division of the age of stone, which immediately preceded in Denmark the age of bronze. It appears that a race more advanced in civilisation, armed with weapons of that mixed metal, invaded Scandinavia and ousted the aborigines.

Lacustrine habitations of Switzerland.—In Switzerland a different class of monuments, illustrating the successive ages of stone, bronze, and iron, has been of late years investigated with great success, and especially since 1854, in which year Dr. F. Keller explored near the shore at Meilen, in the bottom of the lake of Zurich, the ruins of an old village, originally built on numerous wooden piles, driven, at some unknown period, into the muddy bed of the lake. Since then in very many other localities vestiges of and more or less perfect foundations of similar pile-dwellings have been found situate near the borders of the Swiss lakes, at points where the depth of water does not exceed 15 feet.[3] The superficial mud in such cases is filled with various articles, many hundreds of them being often dredged up from a very limited area. Thousands of piles, decayed at their upper extremities, are often met with still firmly fixed in the mud.

As the ages of smooth stone, bronze, and iron merely indicate successive stages of civilisation, they may all have coexisted at once in different parts of the globe, and even in contiguous regions, among nations having little intercourse with each other. To make out, therefore, a distinct chronological series of monuments is only possible when our observations are confined to a limited district, such as Switzerland.

The relative antiquity of the pile-dwellings, which belong respectively to the ages of smooth stone and bronze, is clearly illustrated by the association of the tools with certain groups of animal remains. Where the tools are of stone, the castaway

[3] Bulletin de la Société Vaudoise des Sci. Nat. t. vi. Lausanne, 1860; and Antiquity of Man, by the Author, ch. ii.

bones which served for the food of the ancient people are those of deer, the wild boar, and wild ox, which abounded when society was in the hunter state. But the bones of the later or bronze epoch were chiefly those of the domestic ox, goat, and pig, indicating progress in civilisation. None of the great mammalia or the commonest animals of the antecedent period are found preserved. Some villages of the smooth stone age are of later date than others, and exhibit signs of an improved state of the arts. Among their relics are discovered carbonised grains of wheat and barley, and pieces of bread, proving that the cultivation of cereals had begun. In the same settlements, also, cloth, made of woven flax and straw, has been detected.

The pottery of the bronze age in Switzerland is of a finer texture, and more elegant in form, than that of the age of stone. At Nidau, *on the Lake of Bienne, articles of iron have also been* discovered, so that this settlement was evidently not abandoned till that metal had come into use.

At La Thène, in the northern angle of the Lake Neufchâtel, a great many articles of iron have been obtained, which in form and ornamentation are entirely different both from those of the bronze period and from those used by the Romans. Coins, which sometimes occur in deposits of the age of iron, have never been found in the deposits of the ages of bronze or stone.

The manufacture of bronze was very general over Europe and Asia, and as tin, which enters into this metallic mixture in the proportion of about 10 per cent. to the copper, was not a common metal, and was not found everywhere, commerce must have existed. It is known that Cornwall was traded with late in the age. Very few human bones of the bronze period have been met with in the Danish peat, or in the Swiss lake-dwellings, and this scarcity is generally attributed by archæologists to the custom of burning the dead, which prevailed in the age of bronze.

PLEISTOCENE PERIOD.

From the foregoing observations we may infer that the ages of iron and bronze in Northern and Central Europe were preceded by a stone age, the Neolithic, referable to that division of the post-tertiary epoch which I have called Recent, when the mammalia as well as the other organic remains accompanying the stone implements were of living species. But memorials have been brought to light of a still older age of stone, for which, as above stated, the name Palæolithic has been proposed, when man was contemporary in Europe with the great mammalia, of which the mammoth and hairy rhinoceros are examples, and

with various other animals, many of which have long since died out.

Palæolithic age—Reindeer period.—There are some caves in the departments of Dordogne, Aude, and other parts of the South of France, the contents of which accumulated late in the Palæolithic period. They belong to the 'reindeer period,' because vast quantities of the bones and horns of that deer have been met with. In some cases separate plates of molars of the mammoth, and several teeth of the great Irish deer, *Cervus megáceros*, and of the cave-lion, *Felis spelæa*, an extinct variety of *Felis leo*, have been found mixed up with cut and carved antlers of reindeer. On one of these sculptured bones in the cave of Périgord, a rude representation of the mammoth, with its long curved tusks and long hair and covering of wool, occurs, which is regarded by M. Lartet as placing beyond all doubt the fact that the early inhabitants of these caves must have seen this species of elephant still living in France. The presence of the remains of the marmot, as well as reindeer and some other northern animals, in these caverns seems to imply a colder climate than that of the Swiss lake-dwellings, in which no remains of reindeer have as yet been discovered. The absence of this animal in the old lacustrine habitations of Switzerland is the more significant, because in a cave in the neighbourhood of the Lake of Geneva, namely, that of Mont Salève, bones of the reindeer occur with flint implements similar to those of the caverns of Dordogne and Périgord.

The state of the arts, as exemplified by the instruments found in these caverns of the reindeer period, is much more advanced than that which characterises the tools of the Amiens drift, about to be noticed, but is nevertheless more rude than that of the Swiss lake dwellings. No metallic articles occur, and the stone hatchets are not ground after the fashion of celts; the needles of bone are shaped in a workmanlike style, having their eyes drilled with skill.

The formations above alluded to, which are as yet but imperfectly known, may be classed as belonging to the close of the Palæolithic era, of the monuments of which I am now about to treat.

Alluvial deposits of the Palæolithic age.—The alluvial and marine deposits of the Palæolithic age, the earliest to which any vestiges of man have yet been traced back, belong to a time when the physical geography of Europe differed in a marked degree from that now prevailing. In the Neolithic period, the valleys and rivers coincided almost entirely with those by which the present drainage of the land is effected, and the peat-mosses

were the same as those now growing. The situation of the shell-mounds and lake-dwellings above alluded to is such as to imply that the topography of the districts where they are observed has not subsequently undergone any material alteration. Whereas, we no sooner examine the Pleistocene (Post-pliocene) formations, in which the remains of so many extinct mammalia are found, than we at once perceive a more decided discrepancy between the former and present outline of the surface. Since

Fig. 86.

Section across the Valley of the Ouse, two miles WNW. of Bedford.[4]

1. Oolitic strata.
2. Boulder clay, or marine northern drift, rising to about ninety feet above the Ouse.
3. Ancient gravel, with elephant bones, freshwater shells, and flint implements.
4. Modern alluvium of the Ouse.
a. Biddenham gravel pit, at the bottom of which flint tools were found.

those deposits originated, changes of considerable magnitude have been effected in the depth and width of many valleys, as also in the direction of the superficial and subterranean drainage, and, as is manifest near the sea-coast, in the relative position of land and water.

In the above diagram (fig. 86) is shown the relative position which the gravel, containing flint implements and the bones of extinct animals, bears to the older formations, out of which the valley has been formed. In fig. 87, p. 121, a similar but ideal section was given, illustrating the different positions which the Recent and Pleistocene alluvial deposits occupy in many European valleys.

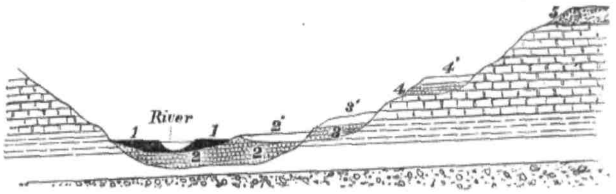
The peat No. 1. (fig. 87) has been formed in a low part of the modern alluvial plain, in parts of which gravel No. 2 of the recent period is seen. Over this gravel the loam or fine sediment 2′ has in many places been deposited by the river during floods which covered nearly the whole alluvial plain.

No. 3 represents an older alluvium, composed of sand and gravel, formed before the valley had been excavated to its present depth. It contains the remains of fluviatile shells of living species associated with the bones of mammalia, in part of

[4] Prestwich, Quart. Jour. Geol. Society, vol. xvii. p. 364, 1861, and Wyatt, 'Geologist,' 1861, p. 242. See Antiquity of Man, p. 215, 1873.

recent, and in part of extinct species. Among the latter the Mammoth (*Elephas primigenius*) and the Hairy Rhinoceros (*R. tichorhinus*) are common. No. 3′ is a remnant of the loam or brick earth by which No. 3 was overspread. No. 4 is a still

Fig. 87.



Ideal section across a river valley.

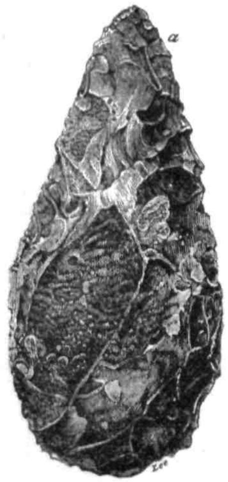
older and more elevated terrace, similar in its composition to No 3, and covered in like manner with its inundation mud (4′). Sometimes some or all of the valley gravels of older date are missing. They usually occur at heights, above the present stream, varying from 10 to 300 feet, sometimes on the right, and sometimes on the left side of and usually on exactly opposite sides of the valley. The upper deposit (5) is the loess of the plateaux ; 4 is termed High-level, and 3 Low-level, gravel.

Among the genera of quadrupeds most frequently met with in England, France, and Germany, the commonest animal remains in the high and low river gravels (4 and 3) are, in England, the Mammoth, Ancient Elephant (*E. antiquus*), Hairy Rhinoceros, Leptorhine Rhinoceros, Horse, Boar, Great Hippopotamus, Bison, Primitive Ox (*Bos primigenius*), Musk Ox, Reindeer, Irish Elk, Red Deer, Cave Lion, Cave Hyæna, Wolf, Grizzly Bear, and Otter. Some of these kinds of animals are extinct, others inhabit Africa and Asia, whilst some are only found within the Arctic circle. Two are N. American. A few kinds still exist on the area. In the peat (No. 1) and in the more modern gravel and silt (No. 2), works of art of the ages of iron and bronze, and of the later or Neolithic stone period, already described, are met with. In the more ancient gravels (3 and 4), there have been found of late years in several valleys in France and England—as, for example, in those of the Seine and Somme, and of the Thames and Ouse, near Bedford—stone implements of a rude type, termed 'Palæolithic,' showing that man coexisted in those districts with the Mammoth and other extinct quadrupeds of the genera above enumerated. In 1847 M. Boucher de Perthes observed in an ancient alluvium at Abbeville, in Picardy, the bones of extinct mammalia associated in such a manner with

flint implements of a rude type as to lead him to infer that both the organic remains and the works of art were referable to one and the same period. This inference was soon after confirmed by Professor Prestwich, who found in 1859 a flint implement *in situ* in the same stratum at Amiens that contained the remains of extinct mammalia. Since that time palæolithic stone implements have been found in many valley gravels on all the continents.

The flint implements found at Abbeville and Amiens (figs. 88 and 89), are different from those commonly called 'celts' (fig. 90). These celts, so often found in the recent formations, have

Fig. 88.



Palæolithic flint implement. St. Acheul. One-third of the original size.

Fig. 89.

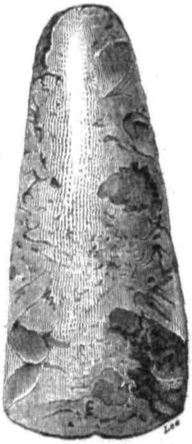
Palæolithic oval-shaped flint implement. Mautort, near Abbeville. One-third of the original size.

a more regular oblong shape, the result of grinding, by which also a sharp edge has been given to them. The Abbeville implements found in gravel at different levels, as in Nos. 3 and 4, fig. 87, in which bones of the Elephant, Rhinoceros, and other extinct mammalia occur, are always unground, having evidently been brought into their present form simply by the chipping off of fragments of flint by repeated blows, such as could be given by another stone.

Some of them are oval, others of a spear-headed form, no two exactly alike, and yet the greater number of each kind are obvi-

ously fashioned after the same general pattern, which is world-wide. Their outer surface is often white, the original black flint having been discoloured and bleached by exposure to the air, or by the action of acids as they lay in the gravel. They are most commonly stained of the same ochreous colour as the flints of the gravel in which they are embedded. Occasionally their antiquity is indicated not only by their colour but by superficial incrustations of carbonate of lime, or by dendrites formed of oxide of iron and manganese. The edges also of most of them are worn, sometimes by having been used as tools, or sometimes by having been rolled in the old river's bed. They are met with not only in the lower-level gravels, as in No. 3, fig. 87, but also in No. 4, or the higher gravels, as at St. Acheul, in the suburbs of Amiens, where the old alluvium lies at an elevation of about 100 feet above the level of the river Somme. At both levels, fluviatile and land-shells are met with in the loam as well as in the gravel, but there are no marine shells associated, except at Abbeville, in the lowest part of the gravel, near the sea, and a few feet only above the present high-water mark. Here with fossil shells of living species are mingled the bones of *Elephas primigenius*, and *E. antiquus*, *Rhinoceros tichorhinus*, *Hippopotamus*, *Felis leo* (var. *spelæa*), *Hyæna crocuta* (var. *spelæa*), Reindeer (*Cervus tarandus*), and many others, the bones accompanying the flint implements in such a manner as to show that both were buried in the old alluvium at the same period.

Fig. 90.



Neolithic polished celt found at Cotton, Cambridgeshire, 1863. One-half of the original size.

Nearly the entire skeleton of a Rhinoceros was found at one point, namely in the Menchecourt drift at Abbeville, the bones being in such juxtaposition as to show that the cartilage must have held them together at the time of their inhumation.

The general absence here and elsewhere of human bones from gravel and sand in which flint tools are discovered, may in some degree be due to the present limited extent of our researches. But it may also be presumed that when a hunter population, always scanty in numbers, ranged over this region, they were too wary to allow themselves to be overtaken by the floods which swept away many herbivorous animals from the low river-plains where they may have been pasturing or sleeping. Beasts of

prey prowling about the same alluvial flats in search of food may also have been surprised more readily than the human tenant of the same region, to whom the signs of a coming tempest were better known.

Inundation-mud of rivers.—Brick-earth.—Fluviatile loam, or loess.—As a general rule, the fluviatile alluvia of different ages (Nos. 2, 3, 4, fig. 87, p. 121) are severally made up of coarse materials in their lower portions, and of fine silt or loam in their upper parts. For rivers are constantly shifting their position in the valley-plain, encroaching gradually on one bank, near which there is deep water, and deserting the other or opposite side, where the channel is growing shallower, being destined eventually to be converted into land. Where the current runs strongest, coarse gravel is swept along, and where its velocity is slackened, first sand, and then only the finest mud, is thrown down. A thin film of this fine sediment is spread, during floods, over a wide area, on one, or sometimes on both sides, of the main stream, often reaching as far as the base of the bluffs or higher grounds which bound the valley. Of such a description are the well-known annual deposits of the Nile, to which Egypt owes its fertility. So thin are they, that the aggregate amount accumulated in a century, is said rarely to exceed five inches, although in the course of thousands of years *it has attained* a vast *thickness, the bottom not having* been reached by borings extending to a depth of 76 feet towards the central parts of the valley. Everywhere it consists of the same homogeneous mud, destitute of stratification—the only signs of successive accumulation being where the Nile has silted up its channel, or where the blown sands of the Libyan desert have invaded the plain, and given rise to alternate layers of sand and mud.

In European river-loams we occasionally observe isolated pebbles and angular pieces of stone which have been floated by ice to the places where they now occur; but no such coarse materials are met with in the plains of Egypt.

In some parts of the valley of the Rhine the accumulation of similar loam, called in Germany 'loess,' or 'lehm,' has taken place on an enormous scale. Its colour is yellowish-grey or reddish, and very homogeneous; and Professor Bischoff has ascertained, by analysis, that it agrees in composition with the mud of the Nile. Although for the most part unstratified, it betrays in some places marks of stratification, especially where it contains calcareous concretions, or in its lower part where it rests on subjacent gravel and sand which alternate with each other near the junction. About a sixth part of the whole mass

is composed of carbonate of lime, and there is usually an intermixture of fine quartzose and micaceous sand.

Although this loess of the Rhine is unsolidified, it usually terminates, where it has been undermined by running water, in a vertical cliff, from the face of which shells of terrestrial, freshwater, and amphibious mollusks project in relief. These shells do not imply the permanent sojourn of a body of fresh water on the spot, for the most aquatic of them, the *Succinea*, inhabits

Fig. 91.

Succinea elongata, nat. size.

Fig. 92.

Pupa muscorum (Linn.), nat. size.

Fig. 93.

Helix hispida (*plebeia*) (Linn.), nat. size.

marshes and wet grassy meadows. The *Succinea elongata* (or *S. oblongata*), fig. 91, is very characteristic both of the loess of the Rhine and of some other European river-loams.

Among the land shells of the Rhenish loess, *Helix hispida*, fig. 93, and *Pupa muscorum*, fig. 92, are very common. Both the terrestrial and aquatic shells are of most fragile and delicate structure, and yet they are almost invariably perfect and uninjured. They must have been broken to pieces had they been swept along by a violent inundation. Even the colour of some of the land-shells, as that of *Helix nemoralis*, is occasionally preserved.

In parts of the valley of the Rhine, between Bingen and Basle, the fluviatile loam or loess now under consideration is several hundred feet thick, and contains here and there throughout that thickness land and amphibious shells. As it is seen in masses fringing both sides of the great plain, and as occasionally remnants of it occur on hills in the centre of the valley, and also forming hills several hundred feet in height, it seems necessary to suppose, first, a time when it slowly accumulated; and secondly, a later period, when large portions of it were removed—that is to say, when the original valley, which had been partially filled up with it, was re-excavated. The greatest altitude of the loess is at Fribourg (284 mètres).

Such changes may have been brought about by a great movement of oscillation, consisting first of a general depression of the land, and then of a gradual re-elevation of the same. The amount of continental depression which first took place in the interior must be imagined to have exceeded that of the region near the sea, in which case the higher part of the great valley

would have its alluvial plain gradually raised by an accumulation of sediment, which would only cease when the subsidence of the land was at an end. If the direction of the movement was then reversed, and, during the re-elevation of the continent, the inland region nearest the mountains should rise more rapidly than that near the coast, the river would acquire a denuding power sufficient to enable it to sweep away, gradually, much of the loess with which parts of its basin had been filled up. Terraces and hillocks of mud and sand would then alone remain to attest the various levels at which the river had thrown down and afterwards removed alluvial matter.

High plateaux gravels and loess.—These are spread far and wide (see fig. 87, No. 5), and are either very distinct in their character or merge gradually into soil above and the parent rock below. In the first instance they contain stones brought from a distance, and this and their covering up equally strata of many kinds, is only explicable by the area of deposit having been at one time below slowly drifting water.

Cavern deposits containing human remains and bones of extinct animals.—In England, and in almost all countries where limestone rocks abound, caverns are found, usually consisting of cavities of large dimensions, connected together by low, narrow, and sometimes tortuous galleries or tunnels. These subterranean conduits are usually filled in part with mud, pebbles, and breccia, in which bones may occur belonging to animals. Some of these bones are referable to extinct and others to living species, and they are occasionally intermingled, as in the valley gravels, with implements of one or other of the great divisions of the stone age, and these are not unfrequently accompanied by human bones, which are very rare in valley alluvium.

Each suite of caverns, and the passages by which they communicate the one with the other, afford memorials to the geologist of successive phases through which they must have passed. First, there was a period when the carbonate of lime was carried out gradually by drainage water containing carbonic acid gas; secondly, an era when engulfed rivers or occasional floods swept organic and inorganic *débris* into the subterranean hollows thus formed; and thirdly, the formation of stalagmite on the floor covering up the deposits.

The quarrying away of large masses of Carboniferous and Devonian limestone, near Liége, in Belgium, has afforded the geologist magnificent sections of some of these caverns, and the former communication of cavities in the interior of the rocks with the old surface of the country, by means of vertical or

oblique fissures, has been demonstrated in places where it would not otherwise have been suspected, so completely have the upper extremities of these fissures been concealed by superficial drift, while their lower ends, which extended into the roofs of the caves, are masked by stalactitic incrustations.

The origin of the stalactite has been noticed (p. 37), and it may now be explained that it is when caverns have ceased to be in a line of active drainage, or to form underground conduits, that a solid floor of hard stalagmite is formed on the bottom.

The late Dr. Schmerling examined forty caves near Liége, and found in all of them the remains of the same fauna, comprising the Mammoth, Tichorhine Rhinoceros, Cave-bear, Cave-hyæna, Cave-lion, Reindeer, and many others, some of extinct and some of living species, and also flint implements. In four or five caves only, parts of human skeletons were met with, comprising sometimes skulls with a few other bones, sometimes nearly every part of the skeleton except the skull. In one of the caves, that of Engihoul, where Schmerling had found the remains of at least three human individuals, they were mingled in such a manner with bones of extinct mammalia, as to leave no doubt on his mind of man having coexisted with them.

The careful investigations carried on by Dr. Falconer, Mr. Pengelly, and others, in the Brixham cave and at Kent's Cavern, near Torquay, demonstrated that flint knives were embedded there in such a manner in red earth underlying a floor of stalagmite as to prove that man had been an inhabitant of that region when the Cave-bear and other members of the ancient Pleistocene fauna were also in existence.

The following are the species which have been discovered in the English caves. Those which are extinct are *Elephas primigenius* and *E. antiquus*, *Rhinoceros tichorinus*, *R. leptorhinus*, *Machairodus*, *Ursus spelæus*, *Cervus megaceros*, *C. Brownii*, *Bison priscus*. The species still living in Africa are the Hippopotamus, Lion and Hyæna. Antilope and *Felis pardis* (Panther) are now Asiatic. The species now living in North America is the Grizzly Bear; and in N. Europe, the Elk, Reindeer, the Lemming, and Glutton. Besides these, there were found the commonest European species, about fourteen in number. It will be observed that several of the above species were found in the river gravels.

The absence of gnawed bones had led Dr. Schmerling to infer that none of the Belgian caves which he explored, had served as the dens of wild beasts; but there are many caves in Germany and England which have certainly been so inhabited, especially by the extinct Hyæna and Bear.

A fine example of a Hyæna's den was afforded by the cave of Kirkdale, so well described by the late Dr. Buckland in his 'Reliquiæ Diluvianæ.' In that cave, above twenty-five miles NNE. of York, the remains of about 300 Hyænas, belonging to individuals of every age, were detected. The species (*Hyæna spelæa*) has been considered by palæontologists as extinct; it was larger than the fierce *Hyæna crocuta* of South Africa, which it closely resembled, and of which it is regarded by Professor Boyd Dawkins as a variety. Dr. Buckland, after carefully examining the spot, proved that the Hyænas must have lived there; a fact attested by the quantity of their dung, which, as in the case of the living Hyæna, is of nearly the same composition as bone, and almost as durable. In the cave were found the remains of the Ox, Mammoth, Hippopotamus, Rhinoceros, Horse, Bear, Wolf, Hare, Water-rat, and several birds. All the bones have the appearance of having been broken and gnawed by the teeth of the Hyænas; and they occur confusedly mixed in loam or mud, or dispersed through a crust of stalagmite which covers it. In these and many other cases it is supposed that portions of herbivorous quadrupeds have been dragged into caverns by beasts of prey, and have served as their food—an opinion quite consistent with the known habits of the living Hyæna.

Australian cave-breccias.—Ossiferous breccias are not confined to Europe, but occur in many other parts of the globe where there are limestone rocks; and those discovered in fissures and caverns in Australia, correspond closely in character with those of Europe, but not in the organic remains.

Some of these caves were examined by the late Sir T. Mitchell in the Wellington Valley, New South Wales, and the breccia contained a great accumulation of bones of animals, none of which have been found beyond the Australian distributional province. On the other hand, no remains of any European or Asiatic animal were found. The bones belonged to those families of Marsupials only, which are now existing in Australia. The animals were gigantic in some instances. The genera *Macropus* (Kangaroo), *Peramales* (Bandicoot), *Phalanger*, *Dasyurus*, and *Phascolomys* (Wombat), were represented by the remains of gigantic and small, extinct and still existing species. A huge animal called *Diprotodon* from its great front teeth, another, the *Nototherium*, and also *Protemnodon* and *Sthenurus* were found, and all were marsupials. An animal called *Thylacoleo* abounded. Of the same geological age as these breccias, are the bogs and swamp beds of the valleys of South Australia and Queensland, which contain *Diprotodon* and other marsupial remains. It is very remarkable that the marsupials only

should have lived in Australia in the Pleistocene age, for they are the only mammalia truly indigenous at the present time. It is one of the many instances of the persistence of a type on the same area, and it indicates long separation from other lands. This law of geographical relationship between the living and fossil vertebrata is extremely interesting, and is not confined to the mammalia only. Thus, when New Zealand was first examined by Europeans, it was found to contain no indigenous land quadrupeds; but a small bird, wingless or with very rudimentary wings, abounded there, the smallest living representative of the Ostrich family, called the Kiwi by the natives (*Apteryx*). In the remains of the Pleistocene period in the same island, there are numerous well-preserved specimens of gigantic birds of the Struthious, or Ostrich order, belonging to genera called by Owen *Dinornis* and *Palapteryx*, which are entombed in superficial deposits. These genera comprehended many species, some of which were four, some seven, others nine, and others eleven feet in height! No contemporary mammalia shared the land with this population of gigantic feathered bipeds.

Mr. Darwin, when describing the recent and fossil mammalia of South America, dwelt much on the wonderful relationship of the extinct to the living types of that part of the world, inferring from such phenomena, that the existing species are all related to the extinct ones which preceded them, by a bond of common descent.

In the Pampas of South America the skeletons of *Megatherium*, *Megalonyx*, *Mylodon*, *Glyptodon*, *Toxodon*, *Macrauchenia*, and other extinct forms, find their nearest analogues in the living Sloth, Armadillo, Cavy, Capybara, and Llama of that continent. The fossil quadrumana, also associated with some of these forms in the Brazilian caves, belong to the Platyrrhine family of monkeys, now peculiar to South America. That the extinct fauna of Buenos Ayres and Brazil was not very ancient, has been shown by its relation to deposits of marine shells, agreeing with those now inhabiting the Atlantic.

Bones of great Carnivora have been found, and also of the Peccary. Moreover, human remains have been got from the Brazilian caves with these bones. It is interesting to note that the Opossum, which is of a marsupial family peculiar to America, is found in these cave breccias, and it is not associated with any Australian kinds, neither on the other hand is any *Didelphys* (Opossum) found in Australia.

The old natural history provinces of this Pleistocene period were limited by natural boundaries and had their characteristic fauna. There was no mixture of European types with the

South American or Australian, and the animals of Asia did not roam to the south, into Australia.

Climate of the Pleistocene Period.—The evidence as to the climate of Europe during this epoch is somewhat conflicting, as may be gleaned from the list of species of animals found in the river gravels (p. 121). The fluviatile and land-shells are all of existing species; but their geographical range has not always been the same as at present. Thus, the Reindeer and the Musk ox (*Ovibos moschatus*), now inhabitants of the Arctic regions, occur fossil in the valleys of the Thames and Avon, and also in France and Germany, accompanied in most places by the Mammoth and the Woolly Rhinoceros. At Grays, in Essex, on the other hand, other species of Elephant and of Rhinoceros occur together with the Hippopotamus and *Cyrena fluminalis*, a shell now extinct in Europe but still an inhabitant of the Nile. With it occurs the *Unio littoralis* now living in the Seine and Loire. In the valley of the Somme flint tools have been found associated with *Hippopotamus major* and *Cyrena fluminalis* in the lower level Pleistocene gravels; while in the higher level (and more ancient) gravels similar tools are more abundant, and are associated with the bones of the Mammoth and other Pleistocene quadrupeds, indicative of a colder climate.

In river-drift at Fisherton, near Salisbury, thirty feet above the river Wiley, the Greenland Lemming and a new species of the Arctic genus *Spermophilus* have been found, along with the Mammoth, Reindeer, Cave-hyæna, and other mammalia suited to a cold climate. A flint implement was taken out from beneath the bones of the Mammoth. In a higher and older deposit in the vicinity, flint tools like those of Amiens have been discovered. Nearly all the known Pleistocene quadrupeds have now been found accompanying flint knives or hatchets in such a way as to imply their coexistence with man; and we have thus the concurrent testimony of several classes of geological facts to the vast antiquity of the human race. In the first place the extinction of many species of large animals, and the disappearance of a great variety of species of wild animals from every part of a wide continent, must have required a vast period for its accomplishment; yet this took place while man existed upon the earth, and was completed before that early period when the Danish shell mounds were formed or the oldest of the Swiss lake-dwellings constructed. Secondly, the deepening and widening of valleys, indicated by the position of the river gravels at various heights, implies an amount of change, of which that which has occurred during the historical period forms

a scarcely perceptible part. Thirdly, the change in the course of rivers which once flowed through caves now removed from any line of drainage, and the formation of solid floors of stalagmite, must have required a great lapse of time. Lastly, ages must have been required to change the climate of wide regions to such an extent as completely to alter the geographical distribution of many mammalia as well as land and freshwater shells. The 3,000 or 4,000 years of the historical period do not furnish us with any appreciable measure for calculating the number of centuries which would suffice for such a series of changes, which are by no means of a local character, but have operated over not only a considerable portion of Europe, but also over every great land surface.

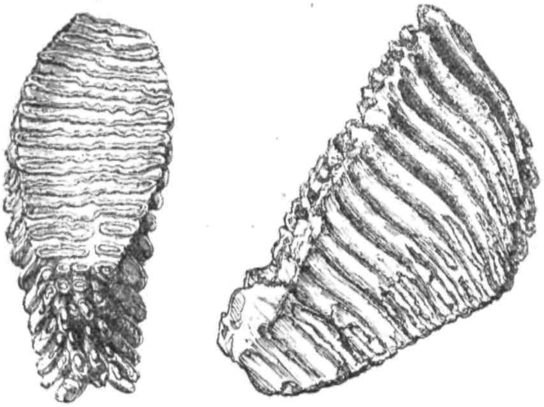
There was evidently a mixture of species of animals during the Pleistocene period in Western Europe and Great Britain, which complicates the question of the climate very much. Some of these species are now living within the Arctic circle, others are equatorial, many persist in the temperate zone. This fauna of very different genera was the outcome of a former and pre-glacial one, which had been driven southwards by the increasing cold, and which gradually spread over its old ground when the mean temperature was increased and the ice of the glacial age retreated.

But it does appear that the summers were hot and short, and that the winters were very long and cold during this part of the Pleistocene. At one period there was a second increase of cold attended by a general extension of all the glaciers which still lingered on, and this probably was the time when the Mammoth, Rhinoceros, and Hippopotamus became extinct, and the Reindeer culminated in numbers.

Relative longevity of species in the mammalia and testacea.—I called attention in 1830 [5] to the fact, which had not at that time attracted notice, that the association in the Pleistocene deposits of shells, exclusively of living species, with many extinct quadrupeds, betokened a longevity of species in the testacea far exceeding that in the mammalia. Subsequent researches seem to show that this greater duration of the same specific forms in the class mollusca is dependent on a still more general law, namely, that the lower the grade of animals, or the greater the simplicity of their structure, the more persistent are they in general in their specific characters throughout vast periods of time. Those mollusca which are of more simple structure have varied at a slower rate than those of a higher and

[5] Principles of Geology, 1st ed. vol. iii. p. 140.

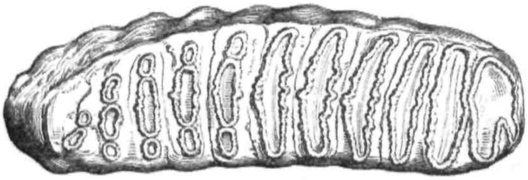
Fig. 94.



Elephas primigenius (or Mammoth). Molar of upper jaw, right side; one-third of natural size. Pleistocene.

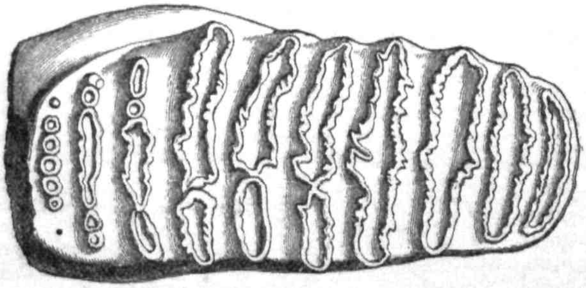
a. grinding surface. *b*. side view.

Fig. 95.



Elephas antiquus, Falconer. Penultimate molar; one-third of natural size Pleistocene and Pliocene.

Fig. 96.



Elephas meridionalis, Nesti. Penultimate molar; one-third of natural size. Pliocene.

more complex organisation; the Brachiopoda, for example, more slowly than the lamellibranchiate bivalves, while the latter have been more persistent than the univalves, whether Gasteropoda or Cephalopoda. In like manner the specific identity of the characters of the Foraminifera, which are among the lowest

Fig. 97.

Rhinoceros leptorhinus, Cuvier. — *R. megarhinus*, Christol; fossil from freshwater beds of Grays, Essex; penultimate molar, lower jaw, left side; two-thirds of nat. size. Pleistocene and Newer Pliocene.

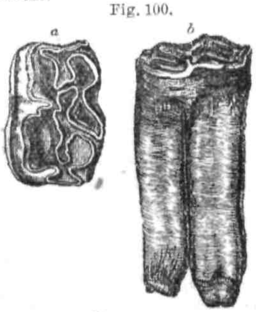
Fig. 98.

Rhinoceros tichorhinus; penultimate molar, lower jaw, left side; two-thirds of nat. size. Pleistocene.

Fig. 99.

Hippopotamus major; from cave near Palermo; molar tooth, two-thirds of nat. size. Pleistocene. Recent.

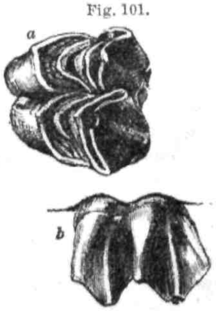
Fig. 100.



Horse.

Equus caballus, L. (common horse); from the shell-marl, Forfarshire; second molar, lower jaw. Recent.
a. grinding surface, two-thirds nat size.
b. side view of same, half nat. size.

Fig. 101.



Deer.

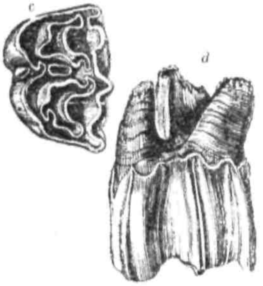
Elk (*Cervus alces*, L.); recent; molar of upper jaw.
a. grinding surface.
b. side view; two-thirds of nat. size.

types of the invertebrata, has outlasted that of the mollusca in an equally decided manner.

Teeth of Pleistocene mammalia.—To those who have never studied comparative anatomy, it may seem scarcely credible that a single bone taken from any part of the skeleton may enable a skilful osteologist to distinguish, in many cases,

the genus, and sometimes the species, of quadrupeds to which it belonged. Although few geologists can aspire to such know-

Fig. 102.



Ox.

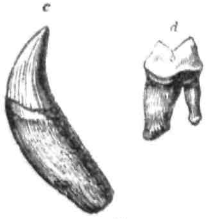
Ox, common, from shell marl, Forfarshire; true molar, upper jaw; two-thirds nat. size. Recent.
c. grinding surface.
d. side view; fangs uppermost.

Fig. 103.

Bear.

a. canine tooth or tusk of bear (*Ursus spelæus*); from cave near Liége.
b. molar of left side, upper jaw, one-third of nat. size. Pleistocene.

Fig. 104.



Tiger.

c. canine tooth of tiger (*Felis tigris*). Recent.
d. outside view of posterior molar, lower jaw; one-third of nat. size. Recent.

Fig. 105.

Hyæna spelæa, Goldf. (variety of *H. crocuta*); part of lower jaw. Kent's Hole, Torquay, Devonshire. One-third nat. size. Pleistocene. Recent. Africa.

Fig. 106.

Teeth of a new species of *Arvicola*, field-mouse, from the Norwich crag. Newer Pliocene.

a. grinding surface. b. side view of same. c. nat. size of a and b.

ledge, which must be the result of long practice and study, they will nevertheless derive great advantage from learning, what is comparatively an easy task, to distinguish the principal

divisions of the mammalia by the forms and characters of their teeth.

The figures on pages 132, 133, 134 represent the teeth of some of the more common species and genera found in alluvial and cavern deposits.

On comparing the grinding surfaces of the corresponding molars of the three species of elephants, figs. 94, 95, 96, it will be seen that the folds of enamel are most numerous in the Mammoth ; fewer and wider, or more open, in *E. antiquus* ; and most open and fewest in *E. meridionalis*, a pliocene form. It will be also seen that the enamel in the molar of the *Rhinoceros tichorhinus* (fig. 98), is much thicker than in that of the *Rhinoceros leptorhinus* (fig. 97).

CHAPTER XI.

PLEISTOCENE PERIOD CONTINUED.—GLACIAL CONDITIONS.[1]

Geographical distribution, form, and characters of glacial drift—Fundamental rocks, polished, grooved, and scratched—Abrading and striating action of glaciers—Moraines, erratic blocks, and 'Roches Moutonnées'—Alpine blocks on the Jura—Continental ice of Greenland—Ancient centres of the dispersion of erratics—Transportation of drift by floating icebergs—Bed of the sea furrowed and polished by the running aground of floating ice.

Character and distribution of glacial drift.—It is now necessary to consider some remarkable deposits which often cover large districts, overlying every kind of strata and formations, and which relate to the age of cold which culminated in the earlier part of the Pleistocene period. In speaking of the loose transported matter commonly found on the surface of the land in all parts of the globe, I alluded to the exceptional character of what has been called the boulder formation in the temperate and Arctic latitudes of the northern hemisphere. The peculiarity of its form in Europe north of the 50th, and in North America north of the 39th parallel of latitude, is now universally attributed to the action of ice, and the difference of opinion respecting it, is now chiefly restricted to the question whether land-ice or floating icebergs have played the chief part

[1] As to the former excess of cold, whether brought about by modifications in the height and distribution of the land or by altered astronomical conditions, see Principles, vol. i. (11th ed. 1872), chaps. xii. and xiii. 'Vicissitudes of Climate.'

in its distribution. It is wanting in the warmer and equatorial regions, and reappears when we examine the lands which lie south of the 40th and 50th parallels in the southern hemisphere, as, for example, in Patagonia, Tierra del Fuego, and New Zealand. It consists of sand and clay, containing a mixture of angular and rounded fragments of rock, of which some may be of large size. It is often wholly devoid of stratification for a depth of 50, 100, or even a greater number of feet, and is occasionally found stratified, especially in the higher parts of the series of deposits, and where sandy beds occur with marine organisms. To the unstratified form of the deposit the name of *till* has long been applied in Scotland, while it is also generally known as 'boulder clay.' The included stones usually have one or more of their sides flattened and smoothed, or even highly polished, the smoothed surfaces usually exhibiting many parallel scratches, one set often crossing an older set. The till is almost everywhere devoid of organic remains, except those washed into it from older formations, but in some places it contains marine shells usually of northern or Arctic species, and frequently in a fragmentary state. The bulk of the till has usually been derived from the grinding down into mud, of rocks in the immediate neighbourhood, so that it is red in a region of Red Sandstone, as in Strathmore in Forfarshire; grey or black in a district of coal and bituminous shale, as around Edinburgh; and white in a chalk country, as in parts of Norfolk and Denmark. The stony fragments dispersed irregularly through the till usually belong, especially in mountainous countries, to rocks found in some part of the same hydrographical basin. But there are regions where the whole of the boulder clay has come from a distance, and huge blocks, or 'erratics,' as they have been called, many feet in diameter, have not unfrequently travelled scores of miles from their point of departure, or from the parent rocks from which they have evidently been detached, and have crossed over the waterpartings of the original and other valleys. These stones are commonly angular, and have often one or more of their sides polished and furrowed.

The rock on which the boulder formation reposes, if it consists of granite, gneiss, limestone, or other hard stone, capable of permanently retaining any superficial markings which may have been imprinted upon it, is usually smoothed or polished, like the erratics above described. It exhibits parallel striæ and furrows having a determinate direction. Such striæ are found at great elevations, and even at 3,000 feet in the Highlands. The direction, both in Europe and North America, agrees gener-

ally in a marked manner with the course taken by the erratic blocks in the same district.

Another form of glacial drift consists of beds of gravel and sand, which usually rest on the boulder clay when the two formations occur together. It is probable that the bulk of this drift had the same origin as the till, but that subsequently the clay and sand have been washed out, and the stones and gravel spread out by currents of water and so worn that they rarely show scratches and polished surfaces. Like the boulder clay, this gravel rarely contains fossils, and when these do occur they are generally in fragments and much waterworn.

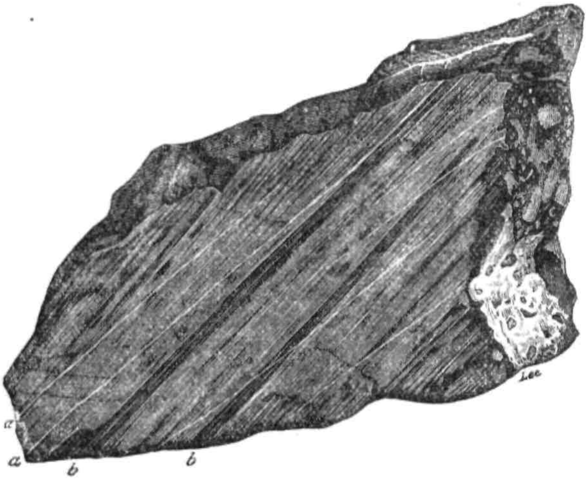
The boulder clay, when it was first studied, seemed in many of its characters so singular and anomalous, that geologists despaired of ever being able to interpret the phenomena by reference to causes now in action. In those exceptional cases, where marine shells of the same date as the boulder clay were found, nearly all of them were recognised as living species, but now flourishing in Arctic latitudes—facts conspiring with the superficial position of the drift to indicate a comparatively modern origin and a great change in climate.

The term '*diluvium*' was for a time the popular name of the boulder formation, because it was referred, by many, to the deluge of Noah, while others retained the name as expressive of their opinion that a series of diluvial waves raised by hurricanes and storms, or by earthquakes, or by the sudden upheaval of land from the bed of the sea, had swept over the continents, carrying with them vast masses of mud and heavy stones, and forcing these stones over rocky surfaces so as to polish and imprint upon them long furrows and striæ. But geologists were not long in seeing that the boulder formation was characteristic of high latitudes, and that on the whole the size and number of erratic blocks increase as we travel towards the Arctic regions. They could not fail to be struck with the contrast which the countries bordering the Baltic presented, when compared with those surrounding the Mediterranean. The multitude of travelled blocks and striated rocks in the one region, and the absence of such appearances in the other, were too obvious to be overlooked. When the nature of glaciers, their movements, denuding and transporting powers were first studied, it was supposed that the terminal moraines, or the collection of mud and angular stone at the foot of the glacier, was the analogue of boulder clay. This is not the case, but it is possible that if the glaciers terminated in the sea, as they do in the Arctic regions in many places, the moraine matter might assume some of the characters of boulder clay. During the late North Polar expedition, an

unctuous clay was frequently found covering the sea floor near glaciers.

Transporting and abrading power of glaciers.—In the higher regions of mountains where the amount of snow that falls in winter so far exceeds the loss in summer, through melting and evaporation, an indefinite thickness would accumulate if it were

Fig. 107.



Limestone, polished, furrowed, and scratched by the glacier of Rosenlaui in Switzerland. (Agassiz.)
a a. White streaks or scratches, caused by small grains of flint frozen into the ice.
b b. Furrows.

not prevented by the formation of nevé. This becoming gradually converted into ice, the glaciers are fed, and they glide down the principal valleys. On the glaciers' surface are seen long lines or heaps of sand and mud, with angular fragments of rock, which fall in quantities from the steep slopes or precipices on either side, where the rocks are daily exposed to great changes of temperature. These deposits being arranged along the sides of the glacier are termed *lateral moraines*. When two glaciers meet, unite and continue their course, the right lateral moraine of the one and the left of the other meet together in the centre of the joint glacier, forming what is called a *medial moraine*. These surface moraines finally fall, or are dropped at the lower end or foot of the glacier, and form the terminal moraine.

Besides the blocks thus carried down on the top of the glacier,

many fall through fissures in the ice, to the bottom, where some of them become firmly frozen into the mass, and are pushed along the base of the glacier, abrading, polishing, and grooving the rocky floor below, as a diamond cuts glass, or as emery powder polishes steel, and the larger blocks are reciprocally grooved and polished by the rocky floor on their lower sides. Some stone becomes included close to the sides of the glacier, and scratches the adjacent rocks, producing long striæ. The striæ which are made, and the deep grooves which are scooped out by this action, are rectilinear and parallel to an extent never seen in those produced on loose stones or rocks, where shingle is hurried along by a torrent, or by the waves on a sea-beach. At the same time a stream of water, produced by the melting of the ice, issues from beneath the glacier charged with mud, derived, not only from the atmospheric waste of the rocks above, but in part also from the crushing of the fragments of stone, which have reached the bottom of the glacier, and the abrasion of its rocky floor.

In addition to these polished, striated, and grooved surfaces of rock, another proof of the former action of a glacier is afforded by the 'roches moutonnées,' or projecting eminences of rock which have been smoothed and worn into the shape of flattened domes by the glacier as it passed over them. They have been traced in the Alps to great heights above the present glaciers, and also to great distances below and beyond them. If the glacier is diminished in length greatly by melting, large angular fragments, which are called 'perched blocks,' are left.

Alpine blocks on the Jura.—The moraines, erratics, polished surfaces, domes, perched blocks, and striæ, above described, are observed in the great valley of Switzerland, fifty miles broad; and on the Jura, a chain which lies to the north of this valley. The average height of the Jura is about one-third that of the Alps, and it is now entirely destitute of glaciers; yet it also presents moraines, and polished and grooved surfaces. The erratics, moreover, which are upon it even to a height of 2,500 feet, present a phenomenon which has astonished and perplexed the geologist for more than half a century. No conclusion can be more incontestable than that these angular blocks of gneiss and other crystalline formations came from the Alps, and that they have been brought for a distance of fifty miles and upwards, across a wide and deep valley; so that they are now lodged on hills composed of sedimentary formations. The great size and angularity which the blocks retained, after a journey of so many leagues, has justly excited wonder; for, many of them are as large as cottages; and one in particular,

composed of gneiss, celebrated under the name of Pierre à Bot, rests on the side of a hill about 900 feet above the lake of Neufchâtel, and is no less than 40 feet in diameter.

The manner in which these erratics were conveyed from the Alps to the Jura was formerly the subject of considerable controversy. M. Venetz proved that the Alpine glaciers must formerly have extended far beyond their present limits, and it was argued that the blocks now found on the Jura had been transported by their agency. Other writers, on the contrary, conjectured that the whole country had been submerged, and that the moraines and erratic blocks must have been transported by floating icebergs, as it was held that the difference in height between the two mountain ranges was not sufficient to have allowed the glaciers to have flowed from the Alps across the wide valley to the Jura. But the definite order in which the Alpine erratics are arranged, and the total absence of marine shells, have gone far to disprove this last hypothesis. Besides, we have no right to assume that the relative heights of the Alps and Jura have remained unaltered since the era of the transportation of the erratics, still less that the change of level which last took place was uniform over a great district, whether in quantity or direction.

In addition to the many evidences of the action of ice in the northern parts of Europe, which we have already mentioned, there occur here and there in some of these countries what are wanting in Switzerland, deposits of marine fossil shells, which exhibit so many forms now characteristic of Arctic seas, that they must have led the geologist to infer the former prevalence of a much colder climate, even had he not encountered so many accompanying signs of ice action. The same marine shells demonstrate the submergence of large areas in Scandinavia and the British Isles during part of the Glacial period.

A characteristic feature of the deposits under consideration in all these countries, is the occurrence of large erratic blocks, and sometimes of moraine matter, in situations remote from lofty mountains, and separated from the nearest points where the parent rocks appear at the surface by great intervening valleys, or arms of the sea. We also often observe striæ and furrows, as in Norway, Sweden and Scotland, which deviate from the direction which they ought to follow if they had been connected with the present line of drainage, and they, therefore, imply the prevalence of a very distinct condition of things at the time when the cold was most intense. The actual state of North Greenland seems to afford the best explanation of such abnormal glacial markings.

Greenland continental ice.—Greenland is a vast unexplored area, and much of it is evidently buried under one continuous and colossal mass of ice that is always moving seaward, a very small part of it in an easterly direction, and all the rest westward, or towards Baffin's Bay. All the minor ridges and valleys are levelled and concealed under a general covering of snow, but here and there some steep mountains protrude abruptly from the icy slope, and a few superficial lines of stones or moraines are visible at certain seasons, when no snow has fallen for many months, and when evaporation, promoted by the wind and sun, has caused much of the upper snow to disappear. The height of this continent is unknown, but it must be considerable, for the most elevated lands of the outskirts attain altitudes of 4,000 to 6,000 feet. The icy slope gradually lowers itself towards the outskirts, and then terminates abruptly in a mass about 2,000 feet in thickness, the great discharge of ice taking place through certain large friths, which are often several miles across at their upper end. The ice is protruded in huge masses, several miles wide, down the western coast, which continue their course, grating along the rocky bottom, like ordinary glaciers, long after they have reached the salt water. When at last they reach a depth of water sufficient to buoy up icebergs from 1,000 to 1,500 feet in vertical thickness, broken masses of them float off into Baffin's Bay, carrying with them on their surface not only fine mud and sand but large stones. These fragments of rock are often polished and scored on one or more sides, and, as the ice melts, they drop down to the bottom of the sea, where large quantities of mud are deposited, and may mingle with the remains of the mollusca which inhabit its bottom. This mud is a sticky clay, and closely resembles some boulder clay; taken with the scratched blocks, it is the analogue of the till.

Although the direction of the ice-streams in Greenland may coincide in the main with that which separate glaciers would take, yet the striation of the surface of the rocks of a continent covered with an ice cap would, on the whole, differ considerably in its minor details from that which would be imprinted on rocks constituting a region of separate glaciers. It is probable that the moving ice cap may sometimes cross deep narrow ravines, or the crests of buried ridges, even at right angles; and glacial striæ and polishing of rocks at great elevations and in remarkable directions are thus accounted for.

Dr. Rink mentions that in North Greenland powerful springs of clayey water escape in winter from under the ice, where it descends to 'the outskirts,' and where, as already stated, it is often 2,000 feet thick—a fact showing how much grinding

action is going on upon the surface of the subjacent rocks. I also learn from Dr. Torell that there are large areas on the outskirts, now no longer covered with permanent snow or glaciers, which exhibit on their surface unmistakeable signs of ancient ice action, so that, vast as is the power now exerted by ice in Greenland, it must once have operated on a still grander scale. The land, though now very elevated, may perhaps have been formerly much higher. It is well known that the south coast of Greenland, from latitude 60° to about 70° N., has, for the last four centuries, been slowly sinking. By this means a surface of rock, well scored and polished by ice, is now slowly subsiding beneath the sea, and is becoming strewed over, as the icebergs melt, with impalpable mud and smoothed and scratched stones. It is not precisely known how far north this downward movement extends.

Drift carried by icebergs.—An account was given so long ago as the year 1822, by Scoresby, of icebergs seen by him in the Arctic seas drifting along in latitudes 69° and 70° N., which rose above the surface from 100 to 200 feet, and some of which measured a mile in circumference. Many of them were loaded with beds of earth and rock, of such thickness that the weight was conjectured to be from 50,000 to 100,000 tons. The bergs have been known to come as far south as 40° N. A similar transportation of rocks is known to be in progress in the southern hemisphere, where boulders included in ice are as frequent as in the north. One of these icebergs was encountered in 1839, in mid-ocean, in the Antarctic regions, many hundred miles from any known land, sailing northwards, with a large erratic block firmly frozen into it. D'Urville found that one of them which he saw floating in the Southern Ocean was 13 miles long and 100 feet high, with walls perfectly vertical, and the top flat. The submerged portions of such bergs must, according to the weight of ice relatively to sea-water, be from six to eight times more considerable than the part which is visible, so that when they are once fairly set in motion, the mechanical force which they might exert against any obstacle standing in their way would be prodigious.

Ice floes which cover a large surface, and are but a few feet above the level of the sea, carry much stone, which falls from the cliffs during the thaw in the high Arctic latitudes. They are carried by currents to the ocean, and dissolve and drop their loads. Erratic blocks and moraine matter will be dispersed somewhat irregularly after reaching the sea, for not only will prevailing winds and marine currents govern the distribution of the drift, but the shape of the submerged area will have its in-

fluence; inasmuch as floating ice, laden with stones, will pass freely through deep water while it will run aground where there are reefs and shallows. In the course of ages such a sea-bed may become densely covered with transported matter, from which some of the adjoining greater depths may be free. If, as in West Greenland, the land is slowly sinking, a large extent of the bottom of the ocean will consist of rock, polished and striated by land-ice, and then overspread by mud and boulders detached from melting bergs.

The mud, sand, and boulders thus let fall in still water, must be devoid of stratification and organic remains. But it may be imagined that occasionally, on the outer side of such packs of stranded bergs, the waves and currents may cause the detached earthy and stony materials to be sorted according to size and weight before they reach the bottom, and to acquire a stratified arrangement. After the emergence, therefore, of such a submarine area, the superficial detritus will have no necessary relation to the hills, valleys, and river-plains over which it will be scattered. Many a watershed may intervene between the starting-point of each erratic or pebble and its final resting-place, and the only means of discovering the country from which it took its departure will consist in a careful comparison of its mineral or fossil contents with those of the parent rocks. Organisms would gather on the sea floor and in its mud, and also boulders and the grounding of icebergs subsequently would destroy the shells or force them up in heaps.

CHAPTER XII.

PLEISTOCENE PERIOD CONTINUED.—GLACIAL CONDITIONS CONCLUDED.

Glaciation of Scotland—Mammoth in Scotch till—Marine shells in Scotch glacial drift—Their Arctic character—Rarity of organic remains in glacial deposits—Contorted strata in drift—List of glacial deposits—Glaciation of Wales and England—Marine shells of Moel Tryfaen—Drift of Ireland—Of Norfolk coast—Chillesford and Aldeby beds—Bridlington drift—Glaciation of Scandinavia and Russia—Glacial formations of North America—India—Connection of the predominance of lakes with glacial action—Fauna of lakes.

Glaciation of Scotland.—Mr. T. F. Jamieson,[1] in 1860, adduced a great body of facts to prove that the Grampians once

[1] Jamieson, Quart. Geol. Journ. 1860, vol. xvi. p. 370.

sent down glaciers from the central regions in all directions towards the sea. 'The glacial grooves,' he observed, 'radiate outwards from the central heights towards all points of the compass, although they do not always strictly conform to the actual shape and contour of the minor valleys and ridges.'

These facts and other characteristics of the Scotch drift lead us to the inference that when the glacial cold first set in, Scotland stood higher above the sea than at present, and was covered for the most part with snow and ice as Greenland is now. This sheet of land-ice, sliding down to lower levels, ground down and polished the subjacent rocks, sweeping off nearly all superficial deposits of older date, and leaving only till and boulders in their place. To this continental state succeeded a period of depression and partial submergence, when the sea advanced over the lower lands, and Scotland was converted into an archipelago.

As the tides and marine currents flowed through what were then wide straits and arms of the sea, it is probable that the boulder clay suffered great waste and furnished the material for the stratified sand and gravel which is now spread over the low ground and sides of the hills up to a height of 2,000 feet, and in places heaped up in those mounds of gravelly drift called 'kames.' Some of the brick earths with Arctic shells have been referred to this epoch, when the climate was still so cold that icebergs large enough to bear huge erratic blocks floated on the sea and mingled their burdens with the gravel at the sea bottom.

Lastly, the land re-emerged from the water, and, reaching a level somewhat above its present heights, became connected with the continent of Europe, glaciers being formed once more in the higher regions, though the ice probably never regained its former extension.[2] After all these changes, there were some minor oscillations in the level of the land, on which, although they have had important geographical consequences, separating Ireland from England, for example, and England from the continent, we need not here enlarge.

Mammoth in Scotch till.—Almost all remains of the terrestrial fauna of the continent which preceded the period of submergence have been lost; but a few patches of estuarine and freshwater formations, containing the seed of the pond-weed *Potamogeton* and *Ranunculus aquatilis*, escaped denudation by submergence. To these belong the peaty clay from which several mammoths' tusks and horns of reindeer were obtained at Kilmaurs in Ayrshire as long ago as 1816. Mr. Bryce in 1865

[2] A. Geikie, Trans. Geol. Soc. Glasgow, vol. i. part 2. 1863.

ascertained that the freshwater formation containing these fossils rests on carboniferous sandstone, and is covered, first by a bed of marine sand with Arctic shells, and then with a great mass of till with glaciated boulders.[3] The incumbent till or boulder-clay is about 40 feet thick, but it often attains much greater thickness in the same part of Scotland.

Marine shells of Scotch drift.—The greatest height to which marine shells have yet been traced in this boulder-clay is at Airdrie in Lanarkshire, ten miles east of Glasgow, 524 feet above the level of the sea. At that spot they were found embedded in stratified clays with till above and below them. There appears no doubt that the overlying deposit was true glacial till, as some boulders of granite were observed in it, which must have come from distances of sixty miles at the least.

The shells figured below are only a few out of a large assemblage of living species, which, taken as a whole, bear

Fig. 108. *Astarte borealis*, Chem. ½. (*A. arctica*, Möll.; *A. compressa*, Mont.)

Fig. 109. *Leda lanceolata* (*oblonga*), Sow. ½.

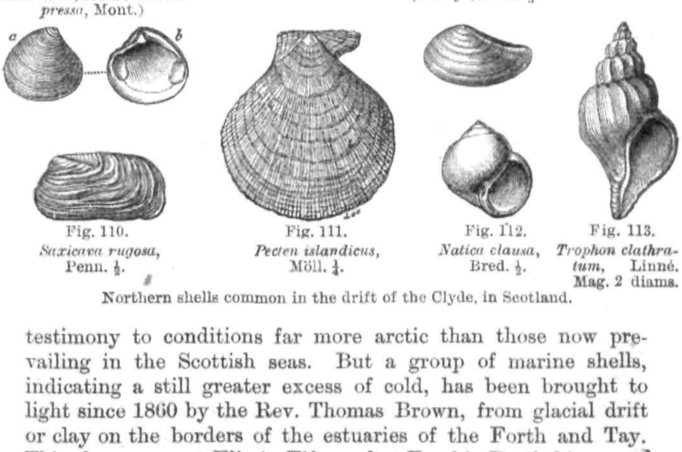


Fig. 110. *Saxicava rugosa*, Penn. ½.

Fig. 111. *Pecten islandicus*, Möll. ¼.

Fig. 112. *Natica clausa*, Bred. ½.

Fig. 113. *Trophon clathratum*, Linné. Mag. 2 diams.

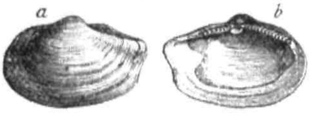
Northern shells common in the drift of the Clyde, in Scotland.

testimony to conditions far more arctic than those now prevailing in the Scottish seas. But a group of marine shells, indicating a still greater excess of cold, has been brought to light since 1860 by the Rev. Thomas Brown, from glacial drift or clay on the borders of the estuaries of the Forth and Tay. This clay occurs at Elie in Fife, and at Errol in Perthshire; and has already afforded about 35 shells, all of living species, and now inhabitants of Arctic regions, such as *Leda truncata*, *Tellina proxima* (see figs. 114, 115), *Pecten Grœnlandicus*, *Crenella lævigata*, *Crenella nigra*, and others, some of them first brought by Captain Sir E. Parry from the coast of Melville Island, latitude 76° N. These were all identified in 1863 by Dr.

[3] Bryce, Quart. Journ. Geol. Soc. vol. xxi. p. 217. 1865.

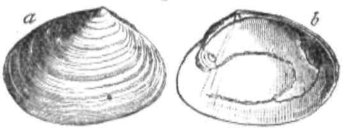
Torell, who had just returned from a survey of the seas around Spitzbergen, where he had collected no less than 150 species of mollusca, living chiefly on a bottom of fine mud derived from the moraines of glaciers which protrude into the sea.

Fig. 114.



Leda truncata.
a. Exterior of left valve.
b. Interior of same.
Nat. size.

Fig. 115.

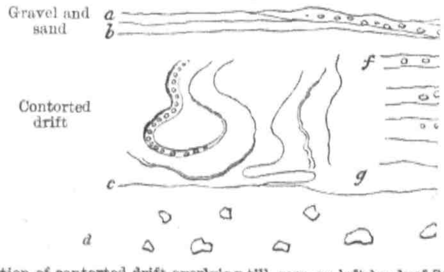


Tellina calcarea, Chem. (*Tellina proxima*, Brown.)
a. Outside of left valve.
b. Interior of same.

He informed me that the fossil fauna of this Scotch glacial deposit exhibits not only the species but also the peculiar varieties of mollusca now characteristic of very high latitudes. Their large size implies that they formerly enjoyed a colder, or, what was to them a more congenial climate, than that now prevailing in the latitude where the fossils occur. Marine shells, nearly all of Arctic species, have been found in the glacial drift of Caithness and Aberdeenshire at heights of 250 feet, and in Banff 350 feet; stratified drift continuous with the above ascends to heights of 500 feet. The temperature of the sea was as low as that of the present Arctic seas.

Contorted strata in drift.—In Scotland the beds of stratified gravel, sand, and clay covering the till are sometimes horizontal

Fig. 116.



Section of contorted drift overlying till, seen on left bank of South Esk, near Cortachie, in 1840. Height of section seen, from *a* to *d*, about 50 feet.

and sometimes contorted for a thickness of several feet. Such contortions are not uncommon in Forfarshire, where I observed them, among other places, in a vertical cutting made in 1840

near the left bank of the South Esk, east of the bridge of Cortachie. The contortions of the beds of fine and coarse sand, gravel, and loam extend through a thickness of no less than 25 feet vertical, or from *b* to *c*, fig. 116, the horizontal stratification being resumed very abruptly at a short distance, as to the right of *f*, *g*. The overlying coarse gravel and sand *a*, is in some places horizontal, in others it exhibits cross bedding, and does not partake of the disturbances which the strata, *b*, *c*, have undergone. In some cases fragments of stratified clays and sands are bent in like manner, in the middle of a great mass of till.

There are indeed many signs in Scotland of the action of floating ice, as might have been expected where proofs of submergence in the Glacial period are present. Among these are the occurrence of large erratic blocks, frequently in clusters at or near the tops of hills or ridges, places which may have formed islets or shallows in the sea where floating ice would mostly ground and discharge its cargo. Land-glaciers would, on the contrary, chiefly discharge their cargoes at the bottom of valleys. Traces of an earlier and independent glaciation have also been observed in some regions where the striation, apparently produced by ice proceeding from the north-west, is not explicable by the radiation of land-ice from a central mountainous region.

Professor A. Geikie, F.R.S., gives the following average succession of glacial phenomena in Scotland in descending order (the oldest at the end) :—

Last traces of glaciers, small moraines at the foot of corries among the higher mountain groups.

Marine terraces, 50 feet and higher ; Clyde beds containing northern mollusca.

Large moraines coming down even to the 50 foot raised beaches.

Erratic blocks.

Sands and gravels—Kame or Esker series, sometimes containing terrestrial organisms, sometimes marine shells.

Upper boulder-clay ; rudely stratified clays with sands and gravels.

Till or boulder-clay ; a stiff, stony, unstratified clay, 100 feet or more in thickness. Contains intercalated beds of fine sand, layers of peat, bones of *Elephas primigenius*, and Reindeer ; also, in some places, boreal marine shells.

Ice-worn rock surfaces.

The presence of the mammoth's (*Elephas primigenius*) tusks and reindeer horns indicates an interglacial period when the land was again occupied by animals.

Glaciation of Wales and England.—In the mountainous districts of the North of England the vestiges of former ice-action are as unequivocal as in Scotland, and point to the former presence of a great thickness of ice spreading outwards to the sea. The direction in which this ice flowed is indicated by the boulders from the Lake district and the Solway Firth which are strewn over the low ground of Anglesea and the Isle of Man. To the eastward the transportation of erratics from Cumberland has been traced by Professor Phillips over a large part of Yorkshire, extending to a height of 1,500 feet above the sea. As in Scotland, it is difficult to say how much of this boulder-clay should be referred to the action of land-glaciers and how much to floating ice during submergence. The East of England, as far south as Suffolk, is bordered by deposits of glacial drift which have been derived from the denudation of the high ground in the North of England as well as the soft strata of the intervening valleys. The greater part of this drift has, no doubt, been deposited under water, as it contains patches of sand with marine shells; and the assemblage in Holderness of erratic blocks from such widely different quarters as Cumberland, Scotland, and Scandinavia, can hardly be explained without calling in the agency of floating ice. The mountains of North Wales were recognised, in 1842, by Dr. Buckland, as having been an independent centre of dispersion for erratics—great glaciers, long since extinct, having radiated from the Snowdonian heights in Carnarvonshire, through seven principal valleys towards as many points of the compass, carrying with them large stony fragments, and grooving the subjacent rocks in as many directions.

Before this evidence of the occurrence of land glaciers had been obtained, Mr. Trimmer had, in 1831, detected the signs of a great submergence in Wales, which happened during the Pleistocene period. He had observed stratified drift, from which he obtained about a dozen species of marine shells, near the summit of Moel Tryfaen, a hill 1,400 feet high on the south side of the Menai Straits. I had an opportunity of examining, in the summer of 1863, in company with the Rev. W. S. Symonds, a long and deep cutting made through this drift. At the top of the hill above mentioned we saw a stratified mass of incoherent sand and gravel 35 feet thick, from which no less than 55 species of mollusca, including 11 Arctic or Northern species, have been obtained by Mr. Darbishire and Dr. J. Gwyn Jeffreys. They belong, without exception, to species still living in British or more northern seas; there being no southern forms. In the lowest beds of this drift were large boulders of

far-transported rocks, glacially polished and scratched on more than one side. Underneath the whole, we saw the edges of vertical slates exposed to view; they were smoothed in places, but there was nowhere a sufficient exposure to enable us to decide whether it was the effect of glaciation or beach erosion. The whole deposit has much the appearance of an accumulation in shallow water or on a beach, and it probably acquired its thickness during the gradual subsidence of the coast—an hypothesis which would require us to ascribe to it a high antiquity, since we must allow time, first for its sinking, and then for its re-elevation.

The height reached by these fossil shells on Moel Tryfaen is no less than 1,300 feet. A marine molluscous fauna, however, agreeing somewhat in character with that of Moel Tryfaen and comprising as many species, was found by Mr. Prestwich, in 1862, at Vale Royal, near Macclesfield, at an elevation between 1,100 and 1,200 feet, and similar patches have been found at lesser heights in other places in central England. The majority of the shells were of kinds now living farther north, and a few were of South of England kinds. Hence the submergence was not restricted to Wales, but included England north of the Thames.

Sir A. Ramsay[4] estimated the probable amount of submergence during some part of the Glacial period at about 2,300 feet.

We have thus obtained proofs of the larger part of England, north of a line drawn from the mouth of the Thames to the Bristol Channel, having been under the sea and traversed by floating ice soon after the commencement of the Glacial epoch. Among illustrative observations, I may allude to the discovery, by Mr. J. F. Bateman, at Mottram, east of Manchester, fifty miles from the sea, and at the height of 568 feet above its level, of till containing rounded and angular stones and marine shells, such as *Turritella communis*, *Purpura lapillus*, *Cardium edule*, and others, among which *Trophon clathratum* (= *Fusus Bamffius*), though still surviving in North British seas, indicates a former cold climate further south. Moreover, glacial deposits occur within a short distance of the north bank of the Thames.

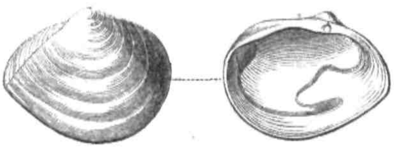
Glacial drift of Ireland.—Marine drift containing the last-mentioned *Nucula* and other glacial shells reaches a height of from 1,000 to 1,200 feet near the Three Rock Mountain, south-east of Dublin, and they are common in the county of Wexford, south of Dublin. More than 80 species have already been

[4] Quart. Journ. Geol. Soc. vol. viii. p. 372. 1852.

obtained from this formation. The great elevation at which these shells occur, and the still greater height to which the surface of the rocks in the mountainous regions of Ireland has been smoothed and striated by ice-action, have led geologists to the opinion that that island, like the greater part of England and Scotland, after having been united with the continent of Europe, from whence it received the plants and animals now inhabiting it, was in great part submerged. The conversion of this and other parts of Great Britain into an archipelago was followed by a re-elevation of land and a second continental period. After all these changes the final separation of Ireland from Great Britain took place, and this event has been supposed to have preceded the opening of the Straits of Dover.[5]

Drift of Norfolk cliffs.—There are deposits of boulder-clay till and sand in these cliffs, principally made up of the waste of white chalk and flints which may be advantageously studied on the coast between Happisburgh and Weyborne, and between Lowestoft and Yarmouth. Here we may see them in vertical

Fig. 117.



Tellina balthica (*T. solidula*), nat. size.

cliffs, sometimes 200 feet and more in height, exposed for a distance of many miles, at the base of part of which the chalk with flints crops out in nearly horizontal strata. A boulder-clay largely composed of fragments of chalk, which is spread over a large part of Norfolk and Suffolk, is exhibited in section at the top of the cliffs near Lowestoft and Yarmouth. It there rests on a thick bed of fine sand called the 'Middle Glacial Sand' by Messrs. S. Wood and Harmer, as they have found it occupying a position intermediate between the chalky boulder-clay and an older glacial drift which is well shown near Cromer. The upper part of the cliff is there composed of beds of sand and loam, often strangely contorted. The contortion was probably produced by the grounding of bergs and floes when they were moving with some rapidity. They sometimes envelope erratics of solid chalk, and more frequently huge masses consisting of chalk which has been crushed and broken into small fragments.

[5] See Antiquity of Man, chap. xiv.

I measured one of these transported blocks in 1839 at Sherringham, and found it to be eighty feet in its longest diameter, with layers of vertical flint. It has been since entirely removed by the waves of the sea. In the floor of the chalk beneath it the layers of flint were horizontal. Such erratics have evidently been moved, bodily, from their original site, probably by the same glacial action which has polished and striated some of the accompanying granitic and other boulders of Scandinavian origin, occasionally six feet in diameter, which are embedded in the drift.

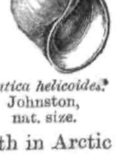
Beneath the contorted drift lies a bed of stiff till containing far-transported and glaciated blocks, but comparatively few fragments of chalk.

With the exception of three species, all the shells found in these deposits are common to a lower series of strata called the Crag (p. 160). Nevertheless, as most of these drifts are barren of fossils, their classification is a matter of difficulty.

The next deposit to be noticed has as yet a very indefinite position in the classification. It may be of the same age as the highest pliocene bed (p. 157), or may be younger. This last age is the position which its mollusca would seem to give it, and therefore the beds about to be noticed are the earliest marine deposits of the Glacial age.

Chillesford and Aldeby beds.—At Chillesford, between Woodbridge and Aldborough, in Suffolk, and Aldeby, near Beccles, in the same county, there occur stratified deposits which are composed of sands and laminated clays, with much mica, forming horizontal beds about twenty feet thick. In the upper part of the laminated clays at Chillesford a skeleton of a whale was found associated with casts of the characteristic shells, *Nucula Cobboldiæ*, *Tellina obliqua*, *Astarte borealis*, and *Cyprina islandica*. The same shells occur in a perfect state in the lower part of the formation. *Natica helicoides* (fig. 118) is an example of a species formerly known only as fossil, but which has now been found living in our seas.

Fig. 118.



Natica helicoides. Johnston, nat. size.

There are at Aldeby 70 species of mollusca, comprising the Chillesford species and some others. Of these about nine-tenths are recent. They are in a perfect state, and clearly indicate a cold climate, as two-thirds of them are now met with in Arctic regions. As a rule, the lamellibranchiate molluscs have both valves united, and many of them, such as *Mya arenaria*, stand with the siphonal end upwards, as when in a living state. *Tellina balthica*, before mentioned (fig. 117) as so characteristic of the glacial beds, including the drift of Bridlington, has not yet

been found in deposits of Chillesford and Aldeby age, whether at Sudbourn, Easton Bavent, Horstead, Coltishall, Burgh, or where they overlie the Norwich Crag proper at Bramerton and Thorpe.

The glacial drift is absent south of the Thames and Bristol Channel, but the south-western counties often present a surface beneath the soil which has been produced by the action of frost on the rocks beneath. In other parts of England the presence of the glacial deposits is by no means universal, and there are many localities and important valleys without a trace of them.

Professor A. Geikie gives the following catalogue of the drift deposits of England, Wales, and Ireland :—

Moraines and raised beaches.

Upper boulder-clay, stiff but sandy, less unstratified than the lower clay, containing marine shells and stones.

Middle sands and gravels, containing marine shells (Moel Tryfaen, Macclesfield in England). In Ireland marine shell deposits at 1,300 feet.

Lower boulder-clay, a stiff clayey deposit full of ice-worn blocks, and equivalent to the till of Scotland.

Bridlington drift.—The so-called crag at Bridlington, containing many mollusca of Arctic kinds, is a mass of old glacial deposit which has been torn up by stranding ice and embedded in boulder-clay.

Erratics near Chichester.—The most southern memorials of ice-action and of a Pleistocene fauna in Great Britain are on the coast of Sussex. A marine deposit exposed between high and low tide occurs on both sides of the promontory called Selsea Bill, in which Mr. Godwin-Austen found thirty-eight species of shells, and the number has since been raised (1873) to a hundred and forty. These erratics and shells were probably brought by ice floating in the English Channel of those days.

This assemblage is interesting because on the whole, while all the species are recent, they have a somewhat more southern aspect than those of the present British Channel. What renders this curious is the fact that the sandy loam in which they occur is overlaid by yellow clayey gravel with large erratic blocks which must have been drifted into their present position by ice when the climate had become much colder. These transported fragments of granite, syenite, and greenstone, as well as of Devonian and Silurian rocks, may have come from the coast of Normandy and Brittany, and are many of them of such large size that we must suppose them to have been drifted into their present site by coast-ice.

Glaciation of Scandinavia and Russia.—In large tracts of

Norway and Sweden, where there have been no glaciers in historical times, the signs of ice-action have been traced as high as 6,000 feet above the level of the sea. These signs consist chiefly of polished and furrowed rock surfaces, of moraines and erratic blocks. The direction of the erratics, like that of the furrows, has usually been conformable to the course of the principal valleys ; but the lines of both sometimes radiate outwards in all directions from the highest land, in a manner which is only explicable by the hypothesis of a general envelope of continental ice, like that of Greenland. Some of the far-transported blocks have been carried from the central parts of Scandinavia towards the Polar regions ; others southwards to Denmark ; some south-westwards, to the coast of Norfolk in England ; others south-eastwards, to Germany.

In the immediate neighbourhood of Upsala, in Sweden, I had observed, in 1834, a ridge of stratified sand and gravel, in the midst of which occurs a layer of marl, evidently formed originally at the bottom of the Baltic, and containing the Mussel, Cockle, and other marine shells of living species, intermixed with some proper to fresh water. The marine shells are all of dwarfish size, like those now inhabiting the brackish waters of the Baltic ; and the marl, in which many of them are embedded, is now raised more than 100 feet above the level of the Gulf of Bothnia. Upon the top of this ridge repose several huge erratics, consisting of gneiss for the most part unrounded, from 9 to 16 feet in diameter, and which must have been brought into their present position since the time when the neighbouring gulf was already characterised by its peculiar fauna. Here, therefore, we have proof that the transport of erratics continued to take place, not merely when the sea was inhabited by the existing testacea, but when the North of Europe had already assumed that remarkable feature of its physical geography, which separates the Baltic from the North Sea, and causes the Gulf of Bothnia to have only one-fourth of the saltness belonging to the ocean. In Denmark, also, recent shells have been found in stratified beds, closely associated with the boulder-clay.

Glacial formations in North America.—In the western hemisphere, both in Canada and as far south as the 40th and even 38th parallel of latitude in the United States, we meet with a repetition of all the peculiarities which distinguish the European boulder formation. Fragments of rock have travelled for great distances, especially from north to south ; the surface of the subjacent rock is smoothed, striated, and fluted ; unstratified mud or *till* containing boulders is associated with strata of loam, sand, and clay, usually devoid of fossils. Where shells are

present, they are of species still living in northern seas, and not a few of them are identical with those belonging to European drift, including most of those already figured, p. 145. The fauna also of the glacial epoch in North America is less rich in species than that now inhabiting the adjacent sea, whether in the Gulf of St. Lawrence, or off the shores of Maine, or in the Bay of Massachusetts.

The extension on the American continent, of the range of erratics during the Post-pliocene period, to lower latitudes than in Europe, agrees well with the present southward deflection of the isothermal lines, or rather the lines of equal winter temperature. It seems that formerly, as now, a more extreme climate and a more abundant supply of ice prevailed on the western side of the Atlantic. Another resemblance between the distribution of the drift fossils in Europe and North America has yet to be pointed out. In Canada and the United States, as in Europe, the marine shells are generally confined to very moderate elevations above the sea (between 100 and 700 feet), while the erratic blocks and the grooved and polished surfaces of rock extend to elevations of several thousand feet.

The rocks which underlie the glacial deposits of North America are well ice-worn, and striæ are found on them at great elevations. The Catskills, which rise from the plain of the Hudson, are found grooved and striated up to near their summits, or to about 3,000 feet. The White Mountains are ice-worn to 5,300 feet.[6]

The **Champlain** series of glacial deposits are unstratified and stratified drifts, and were formed after the boulder-clay. Their lower portion is marine, reaches up the valleys from the coast, and contains *Leda truncata*, *Saxicava rugosa*, and *Tellina Grœnlandica*, with bones of seals and whales. Most of the shells, of which one hundred species are known, are Arctic or boreal, and one half are common to the British glacial beds.

Terraces of marine origin occur on the coast and far inland, from 150 to 500 feet. Inland, the terraces often show four or five platforms, as in the Connecticut Valley.

I have already mentioned that in Europe several quadrupeds of living, as well as extinct, species were common to pre-glacial and post-glacial times. In like manner, there is reason to suppose that in North America much of the ancient mammalian fauna, together with nearly all the invertebrata, lived through the ages of intense cold. That *Mastodon giganteus* was very abundant in the United States after the drift period, is evident from

[6] Geikie, Text-book of Geology, p. 899.

the fact that entire skeletons of this animal are met with in bogs and lacustrine deposits occupying hollows in the glacial drift. They sometimes occur in the bottom even of small ponds recently drained by the agriculturist for the sake of the shell-marl. In 1845 no less than six skeletons of the same species of Mastodon were found in Warren County, New Jersey, six feet below the surface, by a farmer who was digging out the rich mud from a small pond which he had drained. Five of these skeletons were lying together, and most of the bones crumbled to pieces as soon as they were exposed to the air.

It would be rash, however, to infer from such data that these quadrupeds were mired in *modern* times, unless we use that term strictly in a geological sense. I have shown that there is a fluviatile deposit in the valley of the Niagara, containing shells of the genera *Melania*, *Lymnea*, *Planorbis*, *Valvata*, *Cyclas*, *Unio*, *Helix*, &c., all of recent species. From this deposit the bones of the great Mastodon have been taken in a very perfect state. Yet the whole excavation of the ravine, for many miles below the Falls, has been slowly effected since that fluviatile deposit was thrown down. Other extinct animals accompany the *Mastodon giganteus* in the post-glacial deposits of the United States, and this taken with the fact that so few of the mollusca, even of the commencement of the cold period, differ from species now living, is important, as refuting the hypothesis, for which some have contended, that the intensity of the glacial cold annihilated all the species in temperate and Arctic latitudes.

India.—Even in the Himalayas there are relics of the Glacial period, in the presence of vast moraines which extend across valleys at several thousands of feet lower than any moraines do at the present time.

New Zealand.—Hutton states that he does not detect any evidence of the effects of great refrigeration in the fauna of the age of the great extension of the glaciers of New Zealand. Dr. Haart asserts that the old glaciers extended to the plains and far into the sea on the west side of the southern island.

Connection of the predominance of lakes with glacial action.—Generally in countries where the winter cold is intense, such as Canada, Scandinavia, and Finland, even the plains and lowlands are thickly strewn with innumerable ponds and small lakes, together with some others of a larger size ; while in more temperate regions, such as Great Britain, Central and Southern Europe, the United States, and New Zealand, lake districts occur in all such mountainous tracts, as can be proved to have been glaciated in times comparatively modern or since the geographical configuration of the surface bore a considerable resemblance to

that now prevailing. In the same countries lakes abruptly cease beyond the glaciated regions.

A large proportion of the smaller lakes are dammed up at their lower end by barriers of unstratified drift, having the exact character of the moraines of glaciers, and are termed by geologists 'morainic,' but some of them are true rock-basins and would hold water even if all the loose drift now resting on their margins were removed. Glacial action may have formed a few small rock basins, but not the large lakes.

One of the most serious objections to the exclusive origin by ice-erosion of wide and deep lake-basins arises from their capricious distribution, as for example in Piedmont, both to the eastward and westward of Turin, where great lakes are wanting, although some of the largest extinct glaciers descending from Mont Blanc and Monte Rosa came down from the Alps leaving their gigantic moraines in the low country. Here, therefore, we might have expected to find lakes of the first magnitude rivalling the contiguous Lago Maggiore in importance.

A still more striking illustration of the same absence of lakes where large glaciers abound is said to be afforded by the Caucasus, whose loftiest peaks attain heights from 16,000 to 18,000 feet. The present glaciers of this mountain chain are equal or superior in dimensions to those of Switzerland, yet it is remarked by Mr. Freshfield that 'a total absence of lakes, on both sides of the chains, is the most marked feature. Not only are there no great subalpine sheets of water, like Como or Geneva, but mountain tarns, such as the Dauben See, on the Gemmi, or the Klonthal See, near Glarus, are equally wanting.' The Himalayas are singularly free from lakes.

Lakes contain a remarkable fauna; the crustacea have marine affinities, and in some lakes there are seals which cannot pass in by the existing rivers. The great North American lakes have submerged cañons on their floors. The grander lakes are old areas of denudation, depressed or heightened above sea-level by crust movements. They were not formed during the glacial period.

TERTIARY OR CAINOZOIC PERIOD.

CHAPTER XIII.

PLIOCENE PERIOD.

Newer Pliocene—Cromer forest-bed—Its fauna—Norwich Crag—Older Pliocene strata—Red Crag of Suffolk—Coprolitic bed of Red Crag—White or Coralline Crag—Relative age, origin, and climate of the Crag deposits—Belgian Pliocene—Newer Pliocene strata of Sicily—Newer Pliocene strata of the Upper Val d'Arno—Older Pliocene of Italy—Subapennine strata—Older Pliocene flora of Italy—Pliocene of France—German Pliocene—Epplesheim—Vienna basin—Osseous deposits of Pikermi—Pliocene of *India*—*Sivâlik fauna*—*Pliocene of United States.*

It is in the counties of Norfolk, Suffolk, and Essex that we obtain our most valuable information respecting the British Pliocene strata. They have been termed 'Crag,' from a provincial word which is applied to shelly sand.

Newer Pliocene.—The old land surface upon which the glacial deposits collected was necessarily worn and much denuded, and the result has been to destroy nearly every relic of the fauna and flora of the Pre-glacial or Upper Pliocene age in England. But on the eastern coast there are some remarkable deposits which underlie glacial beds, and one in particular at Cromer may be taken as the topmost member of the great formation which accumulated late in the Pliocene period, during a slow process of diminution of mean annual temperature which culminated subsequently in the Glacial age.

Cromer Forest-bed.—Intervening between the glacial formations of Norfolk and the subjacent chalk lies what has been called the Cromer Forest-bed, near the base of a series of freshwater, estuarine, and marine formations. This buried forest has been traced from Cromer to near Kessingland, a distance of more than forty miles, being exposed at certain seasons between high and low water-mark. It is the remains of an old land and estuarine deposit, containing the submerged stumps of trees, which I saw standing erect with their roots in the ancient soil. Associated with the stumps, and overlying them, are lignite beds, with land and freshwater shells of species still inhabiting England, with two exceptions; and the remains of the Waterlily, the Buckbean, and other plants that now live in marshes and ponds.

Through the lignite and forest-bed are scattered cones of the Scotch and Spruce firs with the leaves of the white Water-lily, yellow Pond-lily, Buckthorn, Oak, and Hazel. The fauna is a very suggestive one, and should be compared with that of the river gravels and caves (pp. 121, 127) of the Pleistocene age, and with that of the Pliocene of the Val d'Arno in Italy (p. 171). About fifty mammals, some Reptilia, Amphibia, Fish, and Birds, lived in the age of this pre-glacial deposit. The genera and species studied by Mr. Newton, of the Geological Survey, are *Canis*, *Machairodus*, *Felis*, *Martes sylvaticus*, *Gulo luscus*, *Ursus spelæus*, *U. ferox*, *Trichecus*, *Phoca*, *Equus caballus*, *E. Stenonis*, *Rhinoceros etruscus*, *R. megarhinus*, *Hippopotamus major*, *Sus scrofa*, *Bos primigenius*, *Caprovis*, *Cervus bovides*, *C. capreolus*, *C. elaphus*, *C. megaceros*, and nine other species of Deer, Antilope, *Trogontherium*, *Castor europæus*, *Arvicola*, *Mus sylvestris*, *Talpa*, *Sorex*, *Myogale*, *Elephas meridionalis*, *E. antiquus*, *Balaenoptera*, *Monodon*, *Delphinus*, the common Snake and Viper, Toad, and Triton, the Pike, &c. It is doubtful if *Elephas primigenius* existed then.

The forest-bed is evidently an old land surface, and whilst some geologists reduce it to a clay with rootlets in it, others insist that the stumps of trees found upon it lived and grew there. Mr. Searles Wood, jun., after a long study of the localities, believes that the forest-bed resting on the chalk near Cromer, and which contains the important fauna just noticed, is of Crag age—that is to say, is anterior to any glacial phenomena of importance. He considers that the Chillesford Clay has been worn into a valley at Kessingland, and that the mammalian remains found there, associated with a clay containing rootlets, are newer than those of the Cromer forest-bed.

Mr. C. Reid, of the Geological Survey, believes that all the tree-stumps are drifted specimens. He states that the deposit is covered with a freshwater, and this with a marine deposit. This last contains *Leda myalis*, *Trophon antiquus*, *Nucula Cobboldiæ*. The freshwater deposit has *Unio*, *Paludina*, *Planorbis*, *Limnæa*, *Succinea*, and *Helix* as genera, and *Cyrena fluminalis* and *Belgrandia marginata*, which no longer live on the British area.

There must have been a subsidence of the forest to the amount of 400 or 500 feet, and a re-elevation of the same to an equal extent, in order to allow the ancient surface of the chalk or covering of soil, on which the forest grew, to be first covered with several hundred feet of drift, and then upheaved so that the trees should reach their present level. Although the relative antiquity of the forest-bed to the overlying glacial till is clear, there is some difference of opinion as to its relation to the crag presently to be described.

The remarkable fauna of this Pre-glacial age must have been one that required large roaming grounds, plains, forests, and rivers. The sea must have been close by. It is evident that the animals required a greater mean annual temperature than now occurs, and that many species outlived the Glacial period. Probably a northern fauna mingled with it subsequently, and overspread what was left of the country after the ice had departed.

Norwich or Fluvio-marine Crag.—The Norwich Crag is chiefly seen in the neighbourhood of Norwich, and consists of beds of incoherent sand, loam, and gravel, which are exposed to view on both banks of the Yare, as at Bramerton and Thorpe. As the beds contain a mixture of marine, land, and freshwater shells, with bones of fish and mammalia, it is clear that these beds have been accumulated at the bottom of a sea near the mouth of a river. The beds form patches rarely exceeding twenty feet in thickness, resting on white chalk. At their junction with the chalk there invariably intervenes a bed called the 'Stone-bed,' composed of unrolled chalk flints, commonly of large size, mingled with the remains of a land fauna, comprising

Fig. 119.

Mastodon arvernensis, third milk molar, left side, upper jaw; grinding surface, natural size. Norwich Crag, Postwick, also found in Red Crag, see p. 163.

Mastodon arvernensis, *Elephas meridionalis*, *Elephas antiquus*, *Hippopotamus major*, *Rhinoceros leptorhinus*, *Trogontherium Cuvieri*, and an extinct species of Deer and Horse. Remains of the recent species of Otter and Beaver are found. The Mastodon, which is a species characteristic of the Pliocene strata of Italy and France, is the most abundant fossil, and one not found in the Cromer forest-bed just mentioned. When these flints, probably long exposed in the atmosphere, were submerged, they became covered with Barnacles, and the surface of the chalk

was perforated by the *Pholas crispata*, each fossil shell still remaining at the bottom of its cylindrical cavity, now filled up with loose sand from the incumbent crag. This species of *Pholas* still exists, and drills the rocks between high and low water-mark on the British coast. The name of 'Fluvio-marine' has often been given to this formation, as no less than twenty species of land and freshwater shells have been found in it. They are all of species which still exist; at least only one univalve, a *Paludina*, has any claim to be regarded as extinct.

Of the marine shells, 111 in number, about 17 per cent. are extinct, according to the latest estimate given by Mr. Searles Wood in his Supplement to the Crag Mollusca;[1] but this percentage must be regarded only as provisional. Some of the Arctic shells, which form so large a proportion in the Chillesford and Aldeby beds, are more rare in the Norwich Crag, though many northern species—such as *Rhynchonella psittacea*, *Scalaria Grœnlandica*, *Astarte borealis*, *Panopæa norvegica*, and others—

Fig. 120.

Nucula Cobboldiæ, nat. size.

Fig. 121.

Tellina obliqua, ½.

still occur. The *Nucula Cobboldiæ* and *Tellina obliqua* are frequent in these beds, as are also *Littorina littorea*, *Cardium edule*, and *Turritella communis*, of our seas, proving the littoral origin of the beds.

Doubtful as the order of succession of these beds must be, it is reasonable to infer from the fauna, that the Norwich Crag is the oldest, the Forest-bed next in succession, and the Chillesford clay of still later date (p. 151).

Older Pliocene strata.—Red Crag.—Among the English Pliocene beds the next in antiquity is the Red Crag, which

Fig. 122.

often rests immediately on the London clay, as in the county of Essex, illustrated in the accompanying diagram. In Suffolk it

[1] Palæontographical Society, 1874.

rarely exceeds twenty feet in thickness, and sometimes overlies another Pliocene deposit called the Coralline Crag. It has yielded—exclusive of 87 species regarded by Mr. Wood as derivative—248 species of mollusca, of which 92 per cent. are still living. Thus, apart from its order of superposition, its greater antiquity as a whole than the Norwich, and its still greater antiquity than the glacial beds already described, is proved by the greater departure of its fauna from that of our seas. It may also be observed that in most of the deposits of this Red Crag, the northern forms of the Norwich Crag, and of such glacial formations as Bridlington, are less numerous, while those having a more southern aspect begin to make their appearance. Both the quartzose sand, of which it chiefly consists, and the included shells, are most commonly distinguished by a deep ferruginous or ochreous colour, whence its name. Many of the shells are littoral species. They are often rolled, sometimes comminuted, and the beds have the appearance of having been shifting sandbanks, like those now forming on the Doggerbank, in the sea, sixty miles east of the coast of Northumberland. False bedding, the result of currents, is frequently observable, the planes of the strata being sometimes directed towards one point of the compass, sometimes to the opposite, in beds immediately overlying.

It has long been suspected that the different patches of Red Crag are not all of the same age, although their chronological relation cannot always be decided by superposition. Separate masses are characterised by shells specifically distinct or greatly varying in relative abundance, in a manner implying that the deposits containing them were separated by intervals of time. At Butley, Tunstall, Sudbourn, and in the Red Crag at Chillesford, the mollusca appear to assume their most modern aspect and indicate a colder climate than when the earliest deposits of the same period were formed. At Butley is found *Nucula Cobboldiæ*, so common in the Norwich and certain glacial beds, but unknown in the older parts of the Red Crag. On the other hand, at Walton-on-the-Naze, in Essex, we seem to have an exhibition of the oldest phase of the Red Crag; in which the percentage of extinct forms is almost as great as in the Coralline Crag, and where *Purpura tetragona* (fig. 123) is very abundant. The Walton Crag also indicates a warmer climate, both by the absence of many characteristic Arctic shells that are common in newer portions of the Red Crag, and by a

Fig. 123.

Purpura tetragona Sow., nat. size.

greater proportion of Mediterranean species. *Voluta Lamberti*, an extinct species, which seems to have flourished chiefly in the antecedent Coralline Crag period, is still represented here by individuals of every age.

The reversed Whelk (fig. 126) is common at Walton, where the dextral form of that shell is unknown. Here also specimens of lamellibranchiate molluscs are sometimes found with both the valves united, showing that they belonged to this sea of the Upper Crag, and were not washed in from an older bed, such as the Coralline, in which case the ligament would not have held together the valves in strata so often showing signs of the boisterous action of the waves. Such specimens of united valves are, however, rare. Mr. Searles Wood, after a most assiduous search, has only detected thirteen species in this perfect condition, and among these *Mactra ovalis* alone is common. The true corals found in the Red Crag, indicate a sea with a temperature higher than that of the present German Ocean.

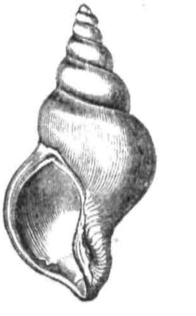
Fig. 124.

Voluta Lamberti, Sow. Variety characteristic of Suffolk Crag. Pliocene.

Fig. 125.

Voluta Lamberti, young individ., Cor. and Red Crag.

Fig. 126.



Trophon antiquum, Müll. (*Fusus contrarius*), half nat. size.

At and near the base of the Red Crag is a loose bed of brown nodules, first noticed by Professor Henslow as containing a large percentage of earthy phosphates. This bed of coprolites (as it is called, because they were originally supposed to be the fæces of animals) does not always occur at one level, but is generally in largest quantity at the junction of the Crag and the underlying formation. In thickness it usually varies from six to eighteen inches, and in some rare cases amounts to many feet. It has been much used in agriculture for manure, as

not only the nodules, but many of the separate bones associated with them, are largely impregnated with phosphate of lime, of which there is sometimes as much as 60 per cent. They are not unfrequently covered with barnacles, showing that they were not formed as concretions in the stratum where they now lie buried, but had been previously consolidated. Amongst the remains are those of *Mastodon arvernensis*, *Mastodon tapiroides*, *Elephas meridionalis*, *Rhinoceros Schleiermacheri*, *Tapirus priscus*, *Hipparion* (a quadruped of the horse family), the antlers of a stag, *Cervus anoceros*, *Hyæna antiqua*, *Felis pardoides*, and a large portion of the skull of a marine animal of the genus *Halitherium* (Dugong), lately recognised by Professor Flower in the collection of the Rev. H. Canham of Waldringfield, and named by him *H. Canhami*. The tusks of a species of Walrus are also met with, together with the teeth of gigantic Sharks and the earbones and other portions of several species of Whales, Dolphins, and other Cetaceans.

The phosphatic nodules often include fossil Crustacea and fishes from the Eocene London clay. Organic remains also of the older chalk and lias have been found, showing how great must have been the denudation of previous formations during the Pliocene period. As the older White Crag, presently to be mentioned, contains similar phosphatic nodules near its base, those of the Red Crag may be partly derived from this and other sources, such as Miocene strata.

White or Coralline Crag.—The lower or Coralline Crag is of very limited extent, ranging over an area about twenty miles in length, and three or four in breadth, between the rivers Stour and Alde, in Suffolk. It is generally calcareous and marly—often a mass of comminuted shells, and the remains of *Bryozoa*, passing occasionally into a soft building-stone. At Sudbourn and Gedgave, near Orford, this building-stone has been largely quarried. At some places in the neighbourhood the softer mass is divided by thin flags of hard limestone, and *Bryozoa* placed in the upright position in which they grew. From the abundance of these Molluscoida the lowest or White Crag obtained its popular name of Coralline Crag; but true corals, or Zoantharia, are very rare in this formation.

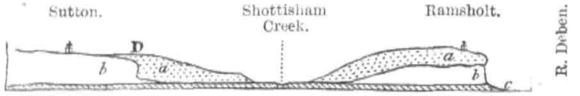
The Coralline Crag rarely, if ever, attains a thickness of thirty feet in any one section. Professor Prestwich, who has thrown more light, than any other writer, on the geology of the Crag, imagines that if the beds found at different localities were united in the probable order of their succession, they might exceed eighty feet in thickness;[2] but since no continuous section

[2] Quart. Journ. Geol. Soc. vol. xxvii. p. 325. 1871.

of any length can be obtained, speculations as to the thickness of the whole deposit must be very vague. A bed of phosphatic nodules, very similar to that before alluded to in the Red Crag, with remains of mammalia, has been met with at the base of the formation at Sutton.

Whenever the Red and Coralline Crag occur in the same district the Red Crag lies uppermost; and, in some cases, as in the section represented in fig. 127, which I had an opportunity

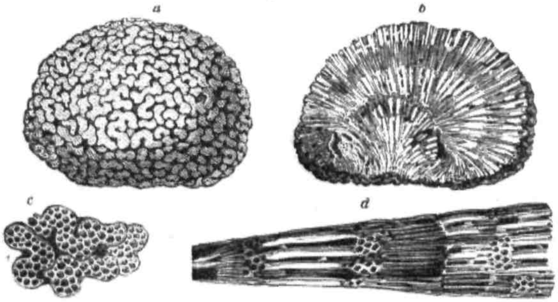
Fig. 127.



Section near Woodbridge, in Suffolk.
a. Red Crag. *b*. Coralline Crag. *c*. London Clay.

of seeing exposed to view in 1839, it is clear that the older deposit or Coralline Crag *b* had suffered denudation, before the newer formation *a* was thrown down upon it. At D there was not only seen a distant cliff, eight or ten feet high, of Coralline Crag, running in a direction N.E and S.W., against which the Red Crag abuts with its horizontal layers, but this cliff occasionally overhangs. The rock composing it is drilled every-

Fig. 128.

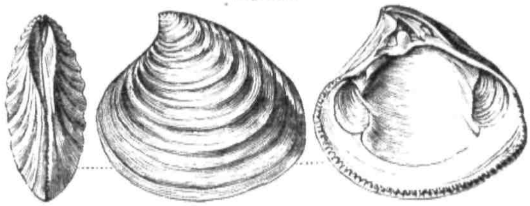


Fascicularia aurantium, Milne Edwards, ½. Family, *Tubuliporidæ*, of same author.
Bryozoan of extinct genus, from the inferior or Coralline Crag, Suffolk.
a. Exterior. *b*. Vertical section of interior. *c*. Portion of exterior magnified.
d. Portion of interior magnified, showing that it is made up of long, thin, straight tubes, united in conical bundles.

where by *Pholades*, the holes which they perforated having been afterwards filled with sand, and covered over when the newer beds were thrown down. The older formation is shown by its fossils to have accumulated in a deeper sea, and contains very

few of those littoral forms such as the Limpet, *Patella*, found in the Red Crag. So great an amount of denudation could scarcely have taken place, in such incoherent materials, without some of the fossils of the inferior beds becoming mixed up

Fig. 129.



Astarte Omalii, Laj., nat. size; species common to Upper and Lower Crag.

with the overlying Red Crag, hence considerable difficulty must be occasionally experienced by the palæontologist in deciding to which bed the species originally belonged.

Mr. Searles Wood estimates the total number of marine testaceous mollusca of the Coralline Crag at 316, of which 84 per cent. are known as living. No less than 130 species of *Bryozoa* have been found in the Coralline Crag, some belonging to genera believed to be now extinct, and of a very peculiar structure; as, for example, that represented in fig. 128, which is one of several species having a globular form. Among the Testacea the genus *Astarte* (see fig. 129) is largely represented,

Fig. 130.

Lingula Dumortieri, Nyst, nat. size; Suffolk and Antwerp Crag.

Fig. 131.

Pyrula reticulata, Lam. Coralline Crag, Ramsholt, ½.

Fig. 132.

Temnechinus excavatus, Forbes; *Temnopleurus excavatus*, Wood; nat. size; Cor. Crag, Ramsholt.

no less than fourteen species being known, and many of them being rich in individuals. There is an absence of genera peculiar to hot climates, such as *Conus*, *Oliva*, *Fasciolaria*, *Crassatella*, and others. The absence also of large cowries (*Cypræa*) is remarkable, those found belonging exclusively to the section *Trivia*. The large Volute, called *Voluta Lamberti* (see fig. 124,

p. 162), may seem an exception; but it differs in form from the Volutes of the torrid zone, and its nearest living ally, *Voluta Junonia*, has been dredged up[3] in the Gulf Stream in extra-tropical latitudes.

The occurrence of a species of *Lingula* at Sutton (see fig. 130) is worthy of remark, as this genus of *Brachiopoda* is now confined to more equatorial latitudes; and the same may be said still more decidedly of a species of *Pyrula*, supposed by Mr. Wood to be identical with *P. reticulata* (fig. 131), now living in the Indian Ocean. A genus also of echinoderms, called by Professor Forbes *Temnechinus* (fig. 132), occurs in the Red and Coralline Crag of Suffolk. Its nearest analogue is in the warm eastern seas of Burmah and of the Western Pacific Islands.

Climate of the Crag Deposits.—One of the most interesting conclusions deduced from a careful comparison of the shells of the British Pliocene strata and the fauna of our present seas was pointed out by Professor E. Forbes. It appears that during the Glacial period, an epoch intermediate, as we have seen, between that of the Crag and our own time, many shells, previously established in the temperate zone, retreated southwards to avoid an uncongenial climate, and they have been found fossil in the Newer Pliocene strata of Sicily, Southern Italy, and the Grecian Archipelago, where they may have experienced, during the era of floating icebergs, a climate resembling that now prevailing in higher European latitudes.[4] The professor gave a list of fifty shells which inhabited the British seas while the Coralline and Red Crag were forming, and which, though now living in our seas, were wanting, as far as was then known, in the glacial deposits. Some few of these species have subsequently been found in the glacial drift, but the general conclusion of Forbes remains unshaken. This view is ably supported by Mr. Searles Wood in the concluding remarks of his Supplement to the Crag Mollusca,[5] where he points out how the geographical changes produced by that sinking down of land which accompanied the Glacial period may have altered the coast line, shutting out a former connection with the Mediterranean, and opening for a time a new one with the Scandinavian seas.[6]

The transport of blocks by ice, when the Red Crag was being deposited, appears to me evident from the huge size of some

[3] Louis Agassiz, Bulltn. of Museum of Comparative Zoology, 1869, p. 263.

[4] E. Forbes, Mem. Geol. Survey Gt. Brit. vol. i. p. 386.

[5] Palæontographical Society, 1873.

[6] For a fuller discussion of the climate of the Crags see Antiquity of Man, 4th ed. 1873, pp. 248–253.

irregular, quite unrounded chalk flints, retaining their white coating, and 2 feet long by 18 inches broad, in beds worked for phosphatic nodules at Foxhall, four miles south-east of Ipswich. These must have been tranquilly drifted to the spot by floating ice. Mr. Prestwich also mentions the occurrence of a large block of porphyry at the base of the Coralline Crag at Sutton, which would imply that the ice-action had begun in our seas even in this older period. The mean annual temperature gradually diminished from the time of the Coralline to that of the Norwich Crag, and the climate became more and more severe, not perhaps without some oscillations of temperature, until it reached its maximum in the Glacial period, or at the beginning of the Pleistocene.

Relation of the Fauna of the Crag to that of the recent Seas.—By far the greater number of the marine species occurring in the several Crag formations are still inhabitants of the British seas; but even these differ considerably in their relative abundance, some of the commonest of the Crag shells being now extremely scarce—as, for example, *Buccinum Dalei*—while others, rarely met with in a fossil state, are now very common, as *Murex erinaceus* and *Cardium echinatum*. Some of the species also, the identity of which with the living would not be disputed by any conchologist, are nevertheless distinguishable as varieties, whether by slight deviations in form or a difference in average dimensions. Since Mr. Searles Wood first described the marine testacea of the Crags, the additions made to that fossil fauna have been considerable, but those made in the same period to our knowledge of the living testacea of the British and Arctic seas and of the Mediterranean have been much greater. By this means the naturalist has been enabled to identify with existing species many forms previously supposed to be extinct. The recent careful deep-sea dredgings of Dr. Carpenter and his companions have led to the discovery of some few Mediterranean species of shells as still living in the abysmal depths of the ocean, which were formerly regarded as extinct members of the Coralline Crag fauna. But in spite of this resuscitation, as it might be called, of a few fossil forms, Mr. Searles Wood finds that they scarcely produce any appreciable difference in the percentage given by him of forms unknown as living. Such generalisations must however always depend on the limits assigned by different naturalists to the terms 'species' and 'variety.'

It appears from the researches of Mr. Searles Wood that the relation of extinct to existing forms is as follows, commencing with the Chillesford beds of early Glacial age.

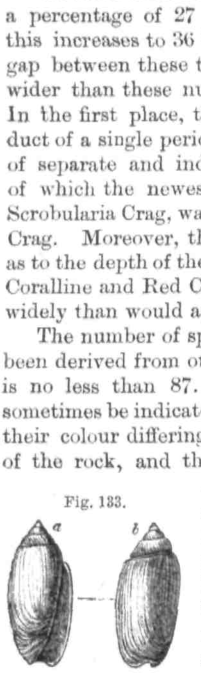
To begin with the uppermost or Chillesford beds, it will be

seen that about 15 per cent. of species of *Mollusca* are extinct, or not known as living; while in the Norwich Crag, which succeeds in the descending order, 16 in 100 are extinct.

To come next to the Red Crag, the reader will observe that a percentage of 27 is given of shells unknown as living, and this increases to 36 in the antecedent Coralline Crag. But the gap between these two stages of our Pliocene deposits is really wider than these numbers would indicate, for several reasons. In the first place, the Coralline Crag is more strictly the product of a single period; the Red Crag, as we have seen, consisted of separate and independent patches, slightly varying in age, of which the newest, or that called by Mr. Searles Wood the Scrobularia Crag, was probably not much anterior to the Norwich Crag. Moreover, there was a great change of conditions, both as to the depth of the sea and climate, between the periods of the Coralline and Red Crag, causing their faunas to differ far more widely than would appear from the above numerical results.

The number of species rejected from the Red Crag as having been derived from other strata, already in existence at the time, is no less than 87. The derivative origin of a species may sometimes be indicated by the extreme scarcity of the individuals, their colour differing from that of the majority and from that of the rock, and their worn condition; whereas an opposite conclusion may be arrived at by the integrity of the shells, especially when they are of delicate and tender structure, or their abundance, and, in the case of the lamellibranchiata by their being held together by the ligament, which often happens when the shells have been so broken that little more than the hinges of the two valves are preserved. Fossils derived from older beds are called remanié.

Fig. 133.



Oliva flammulata, Lmk. Mio-pliocene of Belgium, nat. size. *a*, front view; *b*, back view.

The Pliocene deposits of Belgium, as now limited by Mourlon, consist of a lower division—Système Diestien, at the base of which are sands with great quantities of bones of Cetaceans with excessive elongation of the head (*Heterocetaceæ*). On the ferruginous sands of this system rest sands with *Isocordia cor*, covered by others with *Fusus contrarius*. These two last groups compose the Scaldesian system, and contain a vast quantity of Cetacean remains, with those of fish and also shells.

Beneath the Diestien is the Black Crag, or Antwerp Crag, which is considered to be a passage bed between the Miocene and Pliocene formations. It is rich in Cetacean bones.

Newer Pliocene Strata of Sicily.—At several points north of Catania, on the eastern sea-coast of Sicily—as at Aci-Castello, for example, Trezza, and Nizzeti—marine strata, associated with volcanic tuffs and basaltic lavas, are seen, which belong to a period when the first igneous eruptions of Mount Etna were taking place in a shallow bay of the Mediterranean. They contain numerous fossil shells, and out of 142 species that have been collected, all but eleven are identical with species now living. Some few of these eleven shells may possibly still linger in the depths of the Mediterranean, like *Murex vaginatus* (see fig. 134). On the whole, the modern character of the testaceous fauna under consideration is expressed not only by the small proportion of extinct species, but by the relative number of individuals by which most of the other species are represented, for the proportion agrees with that observed in the present fauna of the Mediterranean. The rarity of individuals in the extinct species is such as to imply that they were already on the point of dying out, having flourished chiefly in the earlier Pliocene times, when the Subapennine strata were in progress.

Fig. 134.

Murex vaginatus, Phil.

Yet since the accumulation of these Newer Pliocene sands and clays, the whole cone of Etna, 11,000 feet in height and about 90 miles in circumference at its base, has been slowly built up; an operation requiring a vast lapse of time, during which modern lavas overwhelmed and enveloped a more ancient cone situated $3\frac{1}{2}$ miles to the east of the present one.[7]

It appears that while Etna was increasing in bulk by a series of eruptions, its whole mass, comprising also its foundations of submarine origin upon which it rests, was undergoing a slow upheaval by which those marine strata were raised to the height of 1,200 feet above the sea, as seen at Catera, and perhaps to greater heights, for we cannot trace their extension westward, owing to the dense and continuous covering of modern lava under which they are buried.

There is probably no part of Europe, where the Newer Pliocene formations enter so largely into the structure of the earth's crust, or rise to such heights above the level of the sea, as Sicily. They cover nearly half the island, and near its centre, at Castrogiovanni, reach an elevation of 3,000 feet. Seguenza has divided the deposits into three groups, the oldest or Zanclean being composed of marls and limestones. Many tropical shells

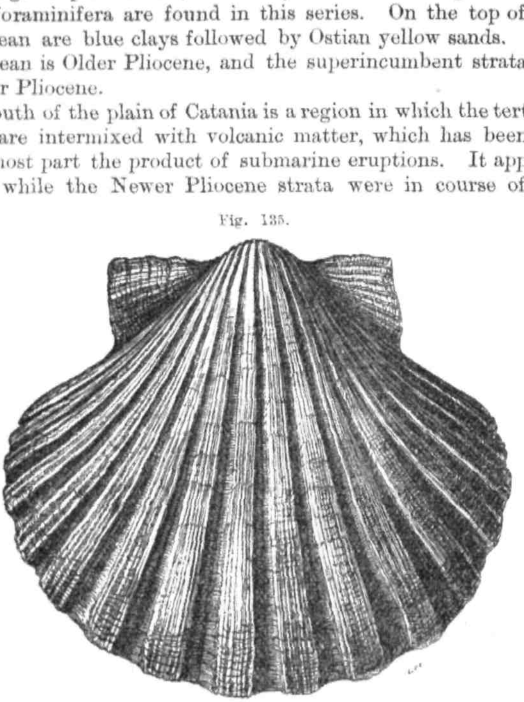
[7] See a Memoir on the Lavas and Mode of Origin of Mount Etna, by the Author, Phil. Trans. 1858.

are found, and out of 504 species about 17 per cent. only are found living in the Mediterranean.

Large tropical shells, and many littoral and deep-sea corals and foraminifera are found in this series. On the top of the Zanclean are blue clays followed by Ostian yellow sands. The Zanclean is Older Pliocene, and the superincumbent strata are Newer Pliocene.

South of the plain of Catania is a region in which the tertiary beds are intermixed with volcanic matter, which has been for the most part the product of submarine eruptions. It appears that, while the Newer Pliocene strata were in course of de-

Fig. 135.



Pecten Jacobæus.

position at the bottom of the sea, volcanoes burst out beneath the waters, like that of Graham Island, in 1831, and these explosions recurred again and again at distant intervals of time. Volcanic ashes and sand were showered down and spread, by the waves and currents, so as to form strata of tuff, which are found intercalated between beds of limestone and clay containing marine shells, the thickness of the whole mass exceeding 2,000 feet.

No shell is more conspicuous in these Sicilian strata than the great scallop, *Pecten Jacobæus* (fig. 135), now so common in the neighbouring seas. The more we reflect on the preponderating number of this and other recent shells, the more we are surprised

at the great thickness, solidity, and height above the sea of the rocky masses in which they are entombed, and the vast amount of geographical change which has taken place since their origin.

It follows, from the modern geological date of these rocks, that the fauna and flora of a large part of Sicily are of higher antiquity than the country itself. The greater part of the island has been raised above the sea during the epoch of existing species, and the animals and plants now inhabiting it must have migrated from adjacent countries, with whose productions the species are now identical.

Newer Pliocene strata of the Upper Val d'Arno.—When we ascend the Arno for about 10 miles above Florence, we arrive at a deep, narrow valley, called the Upper Val d'Arno, which appears once to have been a lake, at a time when the valley below Florence was an arm of the sea. The horizontal lacustrine strata of this upper basin are 12 miles long and 2 broad. The depression which they fill has been excavated out of Eocene and Cretaceous rocks, which form everywhere the sides of the valley in highly inclined stratification. The thickness of the more modern and unconformable beds is about 750 feet, of which the upper 200 feet consist of Newer Pliocene strata, while the lower are Older Pliocene. The newer series are made up of sands and a conglomerate called 'sansino.' Cocchi has found a *Macacus* in them, and a second species has been discovered by Forsyth Major, and these are amongst the last fossil Monkeys of Europe. Among the embedded fossil mammalia are *Mastodon arvernensis*, *Elephas meridionalis*, *Rhinoceros etruscus*, *Hippopotamus major*, and remains of the genera Bear, Hyæna, and Felis, nearly all of which occur in the Cromer forest-bed (see p. 158).

In the same upper strata are found, according to M. Gaudin, the leaves and cones of *Glyptostrobus europæus*, a plant closely allied to *G. heterophyllus*, now inhabiting the north of China and Japan. This conifer had a wide range in time, having been traced back to the Oligocene strata of Switzerland, and being common at Œningen in the Upper Miocene, as we shall see in the sequel (p. 190).

Older Pliocene of Italy.—Subapennine strata.—The Apennines, it is well known, are composed chiefly of Secondary or Mesozoic rocks, forming a chain which branches off from the Ligurian Alps and passes down the middle of the Italian peninsula. At the foot of these mountains, on the side both of the Adriatic and the Mediterranean, are found low hills occupying the space between the older chain and the sea. Their strata belong both to older and newer members of the tertiary series.

The strata, for example, of the Superga, near Turin, are Miocene; those of Asti and Parma Older Pliocene, as is the blue marl of Siena; while the shells of the incumbent yellow sand of the same territory approach more nearly to the recent fauna of the Mediterranean, and may be Newer Pliocene.

We have seen that most of the fossil shells of the Older Pliocene strata of Suffolk which are of recent species are identical with testacea now living in British seas, yet some of them belong to Mediterranean species, and a few even of the genera are those of warmer climates. We might therefore expect, in studying the fossils of corresponding age in countries bordering the Mediterranean, to find some species and genera of warmer latitudes among them. Accordingly, in the marls belonging to this period at Asti, Parma, Siena, and parts of the Tuscan and Roman territories, we observe the genera *Conus*, *Cypræa*, *Strombus*, *Pyrula*, *Mitra*, *Fasciolaria*, *Sigaretus*, *Delphinula*, *Ancillaria*, *Oliva*, *Terebellum*, *Terebra*, *Perna*, *Plicatula*, and *Corbis*, some characteristic of tropical seas, others represented by species more numerous or of larger size than those now proper to the Mediterranean.

Older Pliocene flora of Italy.—The Val d'Arno blue clays, with some subordinate layers of lignite, exhibit a richer flora than the overlying Newer Pliocene beds, and one receding farther from the existing vegetation of Europe. They also comprise more species common to the antecedent Miocene period. Among the genera of flowering plants, M. Gaudin enumerates pine, oak, evergreen oak, plum, plane, alder, elm, fig, laurel, maple, walnut, birch, buckthorn, hiccory, sumach, sarsaparilla, sassafras, cinnamon, *Glyptostrobus*, *Taxodium*, *Sequoia*, *Persea*, *Oreodaphne* (fig. 136), *Cassia*, *Psoralea*, and some others. This assemblage of plants indicates a warm climate, but not so subtropical a one as that of the Upper Miocene period, which will presently be considered.

M. Gaudin, jointly with the Marquis Strozzi, has thrown much light on the botany of beds of the same age in another part of Tuscany, at a place called Montajone, between the rivers Elsa and Evola, where, among other plants, is found the *Oreodaphne Heerii*, Gaud. (see fig. 136), which is probably only a variety of *Oreodaphne fœtens*, or the laurel called the Til in Madeira, where, as in the Canaries, it constitutes a large portion of the native woods, but cannot now endure the climate of Europe. In the fossil specimens the same glands or protuberances are preserved[8] (see fig. 136), as those which are seen in

[8] Contributions à la Flore fossile italienne. Gaudin and Strozzi. Plate 11, fig. 3. Gaudin, p. 22.

the axils of the primary veins of the leaves in the recent Til. Another plant also indicating a warmer climate is the *Liquidambar europæum*, Brong. (see fig. 137), a species nearly allied to *L. styraciflumm*, L., which flourishes in most places in the Southern States of North America, on the borders of the Gulf of Mexico.

In these and subsequent remarks on fossil plants, I shall often use Dr. Lindley's terms, as most familiar in this country ; but as those of M. A. Brongniart are much cited, it may be useful to geologists to give a table explaining the corresponding names of groups so much spoken of in palæontology.

	Brongniart.	Lindley.	
Cryptogamia.	1. Cryptogamous amphigens or cellular cryptogamia.	Thallogens.	Lichens, sea-weeds, fungi.
	2. Cryptogamous acrogens.	Acrogens.	Mosses, horse-tails, ferns, club-mosses,—Lepidodendræ.
Phænerogamia.	3. Dicotyledonous gymnosperms.	Gymnogens.	Conifers and Cycads.
	4. Dicot. angiosperms.	Exogens.	Compositæ, Leguminosæ, Umbelliferæ, Cruciferæ, heaths, &c. All native European trees except Conifers.
	5. Monocotyledons, grasses, &c.	Endogens.	Palms, lilies, aloes, rushes.

Pliocene of France.—There is some difficulty in distinguishing the scattered beds of this age in France from those of the Miocene ; but in some instances there is unconformity between the two series. Some of the deposits of Pliocene age are marine, but the majority are of freshwater and terrestrial origin. At Dixmerie, in Bretagne, there is a sandy deposit in which are fossil shells of species found in the British Crag, but mixed with a preponderance of Miocene forms. In Roussillon a marine deposit contains *Nassa semistriata*, *Turritella vermicolaris*, *Dentalium sexangulosa*, and *Pectunculus glycimeris*. The sands of Landes appear to be of Pliocene age. In the Cotentin there are marls with *Nassa prismatica* and bones of *Halitherium*. It is exceedingly probable that these are all deposits of the age of the Crags, but, owing to the localities being more to the south, the northern element of the testacean fauna does not predominate.

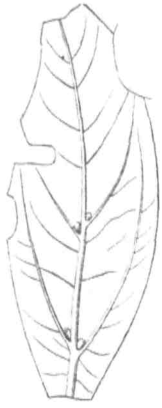
The mammalian fauna of the period was part of a very important continental assemblage of animals, and whilst some of the deposits are of the age of the Forest-bed and Norwich Crag, others are older, and approach the Miocene.

At Saint Prest, near Chartres, the characteristic Pliocene

elephant (*Elephas meridionalis*) is found, with *Rhinoceros etruscus* and *Trogontherium*, associated with *Hippopotamus major*.

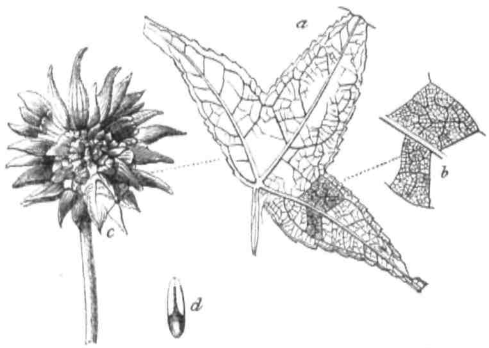
At Montpellier a marine deposit overlies sand with a fossil monkey, *Semnopithecus monopassulancus*, *Mastodon*, *Rhinoceros*

Fig. 136.



Oreodaphne Heerii, Leaf half nat. size.

Fig. 137.



Liquidambar europæum, var. *trilobatum*, A. Br.; sometimes 4-lobed and more commonly 5-lobed.
a. Leaf, half nat. size. *c*. Fruit, nat. size.
b. Part of same, nat. size. *d*. Seed, do. Œningen.

megarhinus, *Tapirus*, *Hyæna*, *Felis*, *Lutra*, *Lagomys*, *Sus*, *Cervus*, *Antilope*, *Hyænarctus*.

In the Auvergne, numerous species of deer, a few antilopes, and *Elephas*, *Hippopotamus*, *Hyæna*, *Hipparion*, and *Machairodus* have been found.

In the valley of the Saone, deposits contain *Elephas meridionalis*, *E. antiquus*, *Mastodon arvernensis*, *M. Borsoni*, *Equus stenonis*; and in the Limagne the same *Mastodons* were accompanied by *Rhinoceros*, *Machairodus*, *Tapirus*, and *Antilope*. The Marnes d'Hauterives, with freshwater shells and Congerian strata of the Valley of the Rhone, rest unconformably on the underlying Miocene.

Count Saporta has examined the Older Pliocene of Maximieux, near Lyons, and found the genera *Bamboo*, *Liquidambar*, *Liriodendron*, *Acer*, *Glyptostrobus*, *Magnolia*, *Populus*, and *Salix*. There was a marked abundance of evergreens, which gives the flora a southern aspect; but with a diminishing mean temperature, the flora became transitional between that of the Miocene and the present day.

German Pliocene.—At Epplesheim, near Worms, there is a group of sands and gravel with lignite, with mammalian remains, overlying a freshwater formation of Late Miocene or Old Pliocene age. The mammalia belong to the genera *Dinotherium*, *Mastodon*, *Rhinoceros* (*incisivus*), *Hippotherium*, *Sus*, *Felis*, and *Cervus*. It is said that the thigh bone of an Ape was found.

Vienna Basin.—The Congerian strata, which contain vast numbers of *Congeria subglobosa*, are sands with the bones of large animals overlying a clay of 300 feet in depth. The fossils indicate Caspian conditions, rather than those of an open sea, and show that there was an inland gulf, with its water gradually becoming brackish and fresh.

As might be expected, masses of rock-salt, gypsum, and anhydrite occur, the result of evaporation of the old sea. The mammalia belonged to the genera *Dinotherium*, *Mastodon*, *Acerotherium*, *Rhinoceros*, *Hippotherium*, *Machairodus*, *Hyæna*, *Cervus*, and *Antilope*. The flora includes conifers of the genera *Sequoia*, *Pinus*, *Glyptostrobus* ; dicotyledons, Birch, Alder, Oak, Beech, Chestnut, Hornbeam, *Liquidambar*, Plane, Laurel, *Cinnamon*, and the Asiatic genus *Parrotia*, and the Australian *Hakea*.

Older Pliocene formations of Greece.—At Pikermi, near Athens, MM. Wagner and Roth have described a deposit in which they found the remains of a great fauna. The whole fauna attests the former extension of a vast expanse of grassy plains where we have now the broken and mountainous country of Greece ; plains, which were probably united with Asia Minor, spreading over the area where the deep Egean Sea and its numerous islands are now situated, and extending into Africa. We are indebted to M. Gaudry, who visited Pikermi, for a treatise on these fossil bones, showing how many data they contribute to the theory of a transition from the mammalia of the Upper Miocene through the Pliocene and Pleistocene forms to those of living genera and species. For example, he recognised an Ape intermediate between the living genera *Semnopithecus* and *Macacus* ; a carnivore intermediate between the hyæna and the civet ; a pachyderm (Hipparion) intermediate between the *Anchitherium* and the horse ; and a ruminant intermediate between the goat and the antilope. One striking feature of the change of the fauna as contrasted with that of the Eocene era is the increased number of species of ruminants as compared to pachyderms. The deposit is now recognised to be above a Pliocene deposit, and to be of Pliocene age.

The Ape *Mesopithecus* is intermediate between the living *Semnopithecus* of India and *Macacus*. The Carnivora belong to

the genera *Machairodus*, several species of *Felis*, *Hyæna*, *Hyænictis*, *Limnocyon*, *Mustela*, *Ictitherium*, *Promephitis*; Rodents, *Hystrix*; Edentata, *Ancylotherium*; Proboscidea, *Mastodon*, *Dinotherium*; Perissodactyla, several species of *Rhinoceros*, *Acerotherium*, *Leptodon*, *Hipparion*; Artiodactyla, *Sus*, *Camelopardalis*, *Helladotherium*, *Antilope*, *Gazelle*, *Palæoryx*, *Palæoreas*, *Dromotherium*. A turtle and a Saurian, and birds of the pheasant tribe and a crane. This remarkable assemblage is characterised by a strong African element.

Pliocene of India.—In India, in the Sind area, there is a succession of Eocene, Oligocene, and Miocene marine strata, covered by freshwater and terrestrial deposits of great thickness, called Manchhar strata. These last are the geological equivalents of the conglomerates,sands, marls, and gravels which flank the Himalayas on the south, and which are called the Sivâlik strata. These are terrestrial and freshwater deposits, and are the results of the denudation of the country during the time when the Himalayas gradually rose into a great mountain mass.

In the Manchhars the following genera of Vertebrata have been discovered:—*Amphycion*, a carnivore; Proboscidea, *Mastodon* (three species), *Dinotherium*; Perissodactyla, *Rhinoceros*, *Acerotherium*; Artiodactyla, *Sus*, *Hemimeryx*, *Sivameryx*, *Chalicotherium*, *Anthracotherium*, *Hyopotamus*, *Hyotherium*, *Dorcotherium;* Edentata, *Manis*; Reptilia, *Crocodilus*, *Chelonia*, *Ophidia*, &c.

The mollusca of the Sivâlik strata, now that the recent forms of India have been studied, turn out to be identical with living forms, or to be closely allied. The genera of Vertebrata are—Quadrumana, *Macacus*, *Semnopithecus*; Carnivora, *Felis*, *Machairodus*, *Pseudaleurus*, *Ictitherium*, *Hyæna*; Canis (*vulpes*), *Amphicyon*, *Ursus*, *Hyænarctus*; Mellivora (*meles*), *Lutra*, *Enhydriodon*; Proboscidea, *Elephas* (three groups), *Mastodon* (three groups); Perissodactyla, *Rhinoceros*, *Acerotherium*, *Listriodon*, *Equus*, *Hipparion*; Artiodactyla, *Hippopotamus*, *Hippopotamodon*, *Tetrocondon*, *Sus*, *Hippohyus*, *Chalicotherium*, *Merycopotamus*, *Cervus*, *Dorcatherium*, *Camelopardalis*, *Sivatherium*, *Hydaspitherium*, *Bos*, *Bison*, *Bubalus*, *Peribos*, *Amphibos*, *Hemibos*, *Antilope*, *Capra*, *Ovis*, *Camelus*; Rodentia, *Rhizomys*, *Hystrix*; Reptilia, *Crocodilus*, *Gharialis*, *Emys*, *Colossochelys*.

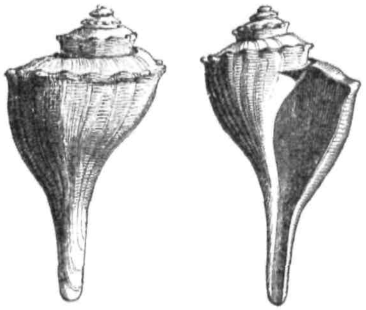
Some of the Sivâlik fauna lived on and lasted during the Pleistocene age, and their remains have been found in the river gravels of the Nerbudda and Godáveri, accompanied by implements of man's making.

Pliocene in the United States.—Between the Alleghany Mountains, formed of older rocks, and the Atlantic, there inter-

venes a low region occupied principally by beds of marl, clay, and sand, consisting of the cretaceous and tertiary formations, and chiefly of the latter. It consists, in the South, as in Georgia, Alabama, and South Carolina, almost exclusively of Eocene deposits; but in North Carolina, Maryland, Virginia, and Delaware more modern strata predominate, of the age of the English Crag and faluns of Touraine.[9]

In the Virginian sands we find in great abundance a species of Astarte (*A. undulata*, Conrad), which resembles closely one

Fig. 138.



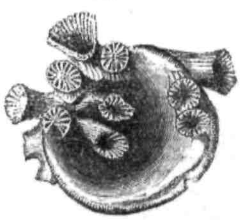
Fulgur canaliculatus, ½. Maryland.

Fig. 139.

Fusus quadricostatus, Say, ½. Maryland.

of the commonest fossils of the Suffolk Crag (*A. Omalii*); the other shells also, of the genera *Natica*, *Fissurella*, *Artemis*, *Lucina*, *Chama*, *Pectunculus*, and *Pecten*, are analogous to shells both of the English Crag and French faluns, although the species are almost all distinct. Out of 147 of these American fossils I could only find thirteen species common to Europe, and these occur partly in the Suffolk Crag, and partly in the faluns of Touraine; but it is an important characteristic of the American group, that it not only contains many peculiar extinct forms, such as *Fusus quadricostatus*, Say (see fig. 139), and *Venus tridacnoides*, abundant in these same formations, but also some shells, which, like *Fulgur Carica* of Say and *F. canaliculatus* (see fig. 138),

Fig. 140.



Astrangia lineata, Lonsdale. Syn. *Cœnangia*. Williamsburg, Virginia.

[9] Proceed. of the Geol. Soc., vol. iv. pt. 3, 1845, p. 547.

Calyptræa costata, *Venus mercenaria*, Lam., *Modiola glandula*, Totten, and *Pecten magellanicus*, Lam., are recent species, yet of forms now confined to the Western side of the Atlantic—a fact implying that some traces of the beginning of the present geographical distribution of mollusca date back to a period as remote as that of the Miocene strata.

In the Carolina States there are from 40 to 60 per cent. of still living species amongst the testacea. Mr Lonsdale examined the corals and found one agreeing generically with a littoral American form (fig. 150).

Among the remains of fish in these strata are several large teeth of the shark family, not distinguishable specifically from fossils of the faluns of Touraine.

Marsh states that east of the Rocky Mountains and on the Pacific coast, the Pliocene deposits rest unconformably on the Miocene, and that there is a well-marked faunal change, modern types of vertebrata making their appearance. He considers that the division between Miocene and Pliocene in Europe is at a higher geological horizon than in America. A true species of *Equus*, not found in the Miocene, characterises the Pliocene of America. No Marsupials are found in the Pliocene deposits; but large Edentata occur in the Lower Pliocene, the genera being *Morotherium*, and possibly *Moropus*. The migration of Edentata was probably from north to south, and the post-Pliocene Edentata of North America are of the same genera as those of South America—*Megatherium*, *Mylodon*, *Megalonyx* (p. 129). Amongst the Equine group, *Protohippus* with three toes to each foot was as large as an ass; and *Pliohippus* is without the extra toe, and is a true horse. *Equus* is present, but became extinct, for no horses were found by the first colonists of America from Europe. *Diceratherium* and other large Rhinoceridæ occur, and all became extinct before the post-Pliocene. The genera *Tapirus* is found in the post-Tertiary deposits, and probably existed during the Pliocene.

All the pig tribe in the Pliocene, are closely related to the Peccaries, and no true pig nor *Hippopotamus* has been found. The ruminating hogs existed, and there were the genera *Merychochærus* and *Merychyus*, but they became extinct at the close of the period. Deer and bison occur, but no sheep or goats.

Mastodon appears in the Lower Pliocene and lived on into the Pleistocene, and *Elephas* came in with the Newer Pliocene. The Carnivora genera *Canis*, *Machairodus*, *Leptarctus*, and *Ursus* occurred. No remains of primates have been found, however.

In the Upper Missouri region there are freshwater beds—the Loup River group of Meek and Hayden or Niobara of Marsh,

containing many vertebrate remains of the genera *Mastodon*, *Elephas*, *Rhinoceros*, *Felis*, *Procamelus*, *Homocamelus*, *Protohippus*, *Equus*.

The Californian auriferous gravels of the Sierra Nevada, capped by basalt, are probably of this age.

In the Old World great changes in the physical geography of Europe and Asia occurred during and at the close of the Pliocene. The Alpine and Himalayan mountain systems were completed, and the main lines of the great rivers were indicated.

CHAPTER XIV.

MIOCENE PERIOD.

Miocene strata of France—Faluns of Touraine—Tropical climate implied by testacea—Proportion of recent species of shells—Faluns more ancient than the Suffolk Crag—Miocene of Bordeaux and the South of France—Miocene of Œningen in Switzerland—Plants of the Upper freshwater Molasse—Fossil fruit and flowers as well as leaves—Insects of the Upper Molasse—Middle or Marine Molasse of Switzerland—Miocene beds of the Vienna basin—Mayence basin—Miocene of Italy and Greece—Miocene of the United States—Miocene of India.

No British strata have a distinct claim to be regarded as Miocene, and we must refer to foreign examples in illustration of this important period in the earth's history.

Miocene strata of France.—Faluns of Touraine.—The strata which we meet with next in the descending order are those called by many geologists 'Middle Tertiary,' for which in 1833 I proposed the name of Miocene, selecting the 'faluns' of the valley of the Loire in France as my example or type.

Probably Great Britain was a land surface during this period. The term 'faluns' is given provincially by French agriculturists to shelly sand and marl spread over the land in Touraine, just as the similar shelly deposits called Crag were formerly much used in Suffolk to fertilise the soil, before the coprolitic or phosphatic nodules came into use. Isolated masses of such faluns occur from near the mouth of the Loire, in the neighbourhood of Nantes, to as far inland as a district south of Tours. They are also found at Pontlevoy, on the Cher, about seventy miles above the junction of that river with the Loire, and thirty miles S.E. of Tours. Deposits of the same age also appear under different mineral conditions near the towns of Dinan and Rennes,

in Brittany. The scattered patches of faluns are of slight thickness, rarely exceeding fifty feet; and between the district called La Sologne and the sea they repose on a great variety of older rocks; being seen to rest successively upon gneiss, clay slate, various secondary formations, including the chalk; and lastly, upon the upper fresh-water limestone of the Parisian tertiary series, which, as before mentioned (p. 111), stretches continuously from the basin of the Seine to that of the Loire, and which is of Oligocene age.

At some points, as at Louans, south of Tours, the shells are stained of a ferruginous colour, not unlike those of the Red Crag of Suffolk. The species are, for the most part, marine, but a few of them belong to land and fluviatile genera. Among the land forms *Helix turonensis* (fig. 38, p. 32) is the most abundant. Remains of terrestrial quadrupeds are here and there intermixed, belonging to the genera *Dinotherium* (fig. 141), *Mastodon*, *Rhinoceros*, *Hippopotamus*, *Chæropotamus*, *Dichobune*, Deer, and others, and these are accompanied by Cetacea of extinct species.

Fig. 141.

Dinotherium giganteum, Kaup.

The fossil testacea of the faluns of the Loire imply, according to the late Edward Forbes, that the beds were formed partly on the shore itself at the level of low water, and partly at very moderate depths, not exceeding ten fathoms below that level. The fauna indicates that the climate was warmer than that of Europe at the present time. Thus it contains seven species of *Cypræa*, some larger than any existing cowry of the Mediterranean, several species of *Oliva*, *Ancillaria*, *Mitra*, *Terebra*, *Pyrula*, *Fasciolaria*, and *Conus*. Of the cones there are no less than eight species, some very large, whereas the only European cone now living is of diminutive size. The genus *Nerita*, and many others, are also represented by individuals of a type now characteristic of equatorial seas, and wholly unlike any Mediterranean forms. These proofs of a more elevated temperature, seem to imply the higher antiquity of the faluns as compared with the Suffolk Crag, and are in perfect accordance with the fact of the smaller proportion of testacea of recent species found in the faluns.

Out of 290 species of shells, collected by myself in 1840 at

Pontlevoy, Louans, Bossée, and other villages twenty miles south of Tours, and at Savigné, about fifteen miles north-west of that place, seventy-two only could be identified with recent species, which is in the proportion of twenty-five per cent.

The principal grounds for referring the English Crag to the Older Pliocene and the French faluns to the Miocene epochs, consist in the predominance of fossil shells in the British strata identifiable with species, not only still living, but which are now inhabitants of neighbouring seas, while the accompanying extinct species are of genera such as characterise Europe. In the faluns, on the contrary, the recent species are in a decided minority; and most of them are now inhabitants of the Mediterranean, the coast of Africa, and the Indian Ocean; in a word, less northern in character, and pointing to the prevalence of a warmer climate. They indicate a state of things receding farther from the present condition of Central Europe in physical geography and climate, and doubtless, therefore, receding farther from our era in time.

Among the conspicuous fossils common to the faluns of the Loire and the Suffolk Crag, is a variety of the *Voluta Lamberti*, a shell already alluded to (p. 162, fig. 124). The specimens of this shell which I have myself collected in Touraine, or have seen in museums, are thicker and heavier than British individuals of the same species, and shorter in proportion to their width, and have the folds on the columella less oblique, as represented in the annexed figure.

Fig. 142.

Voluta Lamberti, Sow., ½. Variety characteristic of Faluns of Touraine. Miocene.

Miocene strata of Bordeaux and South of France.—A great extent of country between the Pyrenees and the Gironde is overspread by tertiary deposits of various ages and chiefly of Miocene date. Some of these, near Bordeaux, coincide in age with the faluns of Touraine, already mentioned, but many of the species of shells are peculiar to the south. The succession of beds in the basin of the Gironde implies several oscillations of level by which the same wide area was alternately converted into sea and land and into brackish-water lagoons, and finally into freshwater ponds and lakes.

Among the freshwater strata of this age near the base of the Pyrenees are marls, limestones, and sands, in which the eminent comparative anatomist, M. Lartet, obtained a great number of

fossil mammalia common to the faluns of the Loire and the Miocene beds of Switzerland, such as *Dinotherium giganteum* and *Mastodon angustidens*. More lately M. Gaudry has enumerated 16 species of vertebrata from strata of this age at Mont Léberon in Vaucluse, among which are *Machairodus cultridens*, *Rhinoceros Schleiermacheri*, *Dinotherium giganteum*, and the gigantic ruminant *Helladotherium Duvernoyi*, rivalling the Giraffe in stature. This herbivore had a wide range over Europe and Asia, its remains having been found in Greece and India. But the most remarkable of all the remains found in the Miocene strata of the South of France were the bones of quadrumana, or of the ape and monkey tribe, which were discovered by M. Lartet in 1837, the first of that order of quadrupeds detected in Europe. They occurred at Sansan, near Auch, in the Department of Gers, in latitude 43° 39′ N., about forty miles west of Toulouse. They were referred by MM. Lartet and Blainville to a genus closely allied to the Gibbon, to which they gave the name of *Pliopithecus*. When I visited Sansan in the spring of 1872 I came to the conclusion that the explanation of so many mammalia and other vertebrata being preserved at Sansan alone, in so very limited an area, was probably the partial recurrence of a very thick impervious marly deposit or layer in which the quadrupeds may have been bogged, and which prevented free percolation of water, whereas in general impervious beds must have been wanting, so that all organic remains of the date of the faluns were destroyed where they happened to be imbedded.

In 1856, M. Lartet described another species of the same family of long-armed apes (*Hylobates*), which he obtained from strata of the same age at Saint Gaudens in the Haute-Garonne. The fossil remains of this animal consisted of a portion of a lower jaw with teeth and the shaft of a humerus. It is supposed to have been a tree-climbing frugivorous ape, equalling Man in stature. As the trunks of oaks are common in the lignite beds in which it lay, it has received the generic name of *Dryopithecus*. The angle formed by the ascending ramus of the jaw and the alveolar border is less open, and therefore more like the human subject, than the Chimpanzee ; and, what is still more remarkable, the fossil, a young but adult individual, had all its milk teeth replaced by the second set, while its last true molar (or wisdom tooth) was still undeveloped, or only existed as a germ in the jaw-bone. In the mode, therefore, of the succession of its teeth it differed from the Gorilla and Chimpanzee, and corresponded with the human species.

Miocene beds of Œningen in Switzerland.—In Switzer-

land, deposits of the same age as the Faluns have been discovered, which are remarkable for their botanical and entomological treasures. We are indebted to Professor Heer of Zürich for the description, restoration, and classification of several hundred species and varieties of these fossil plants, the whole of which he has illustrated by excellent figures in his 'Flora Tertiaria Helvetiæ.' The careful studies by Heer, A. Brongniart, Meyer, Goeppert, Ettinghausen, Gardner, and other palæobotanists, have established the affinities of the former and existing floras, and have produced some very remarkable generalizations regarding the former distribution of plants and the ancient climates. But great discrepancies of opinion have arisen, and the late careful researches of Lesquereux and Gardner have modified the conclusions of the earlier palæobotanists regarding the age of many floras.

When we begin by studying the fossils of the Newer Pliocene deposits, such as those of the Upper Val d'Arno, before alluded to, we perceive that the fossil foliage agrees almost entirely with the trees and shrubs of a modern European forest. In the plants of the Older Pliocene strata of the same region we observe a larger proportion of species and genera which, although they may agree with well-known Asiatic or other foreign types, are at present wanting in Italy. If we then examine the Miocene formations of the same country, exotic forms become more abundant, especially the palms, whether they belong to the European or American fan-palms, *Chamærops* and *Sabal* (fig. 154, p. 204), or to the more tropical family of the date-palms or *Phœnicites*, which last are conspicuous in the Oligocene beds of Central Europe. Although we have not found the fruit or flower of these palms in a fossil state, the leaves are so characteristic that no one doubts the family to which they belong, or hesitates to accept them as indications of a warm and sub-tropical climate. Too much reliance was placed formerly upon the presence or absence of dicotyledonous leaves, and the existence of Palms, Figs, *Araucariæ*, and *Proteaceæ* in deciding upon the age of strata containing plant remains. Moreover, floras very widely separated by latitude were attempted to be correlated upon insufficient evidence, and no allowance was made for modifications in the general climate of the Northern Hemisphere during the Tertiary ages. The tendency of the opinion of the palæobotanists of this day is to place the fossil tertiary plants lower in the series than formerly. There are, of course, exceptions, and it is indeed fortunate that there are some floras described the geological position of which is beyond doubt. Thus flora of Œningen is Miocene; that of Sheppey,

Bournemouth, and Reading is Eocene; the leaf-beds of Aix-la-Chapelle are Upper Cretaceous, and the age of the Western American floras is undoubted. Hence there are types with which to compare distinct floras, due allowance being made for climate and latitude in the comparison. The plants have existed longer on the earth without great change than the animals, and whilst the palæontological break between the Secondary and the Tertiary formations is vast from the animal point of view, it is not very apparent botanically. It is evident that no great conclusions can be derived from the study of leaves alone, for the fruit and flower are absolutely necessary to identify species correctly. Nevertheless, a rough comparison may be instituted by the study of leaves.

The Miocene formations of Switzerland have been called *Molasse*, a term derived from the French *mol*, and applied to a *soft*, incoherent, greenish sandstone, occupying the country between the Alps and the Jura. This Miocene molasse comprises three divisions, of which the middle one is marine, and, being closely related by its shells to the faluns of Touraine, may be classed as Upper Miocene. The two others are freshwater, the upper of which may be also grouped with the faluns, while the lower must be referred to the Oligocene, as defined in the next chapter.

Upper Miocene freshwater Molasse.—This formation is best seen at Œningen, in the valley of the Rhine, between Constance and Schaffhausen, a locality celebrated for having produced in the year 1700 the supposed human skeleton called by Scheuchzer 'homo diluvii testis,' a fossil afterwards demonstrated by Cuvier to be a reptile, or aquatic salamander, of larger dimensions than even its great living representative the salamander of Japan.

The Œningen strata consist of a series of sandstones, marls, and limestones, many of them thinly laminated, and which appear to have slowly accumulated in a lake probably fed by springs holding carbonate of lime in solution. The organic remains have been chiefly derived from two quarries, the lower of which is about 550 feet above the level of the Lake of Constance, while the upper quarry is 150 feet higher. In this last, a section thirty feet deep, displays a great succession of beds, most of them splitting into slabs, and some into very thin laminæ. Twenty-one beds are enumerated by Professor Heer, the uppermost a bluish-grey marl seven feet thick, with organic remains, resting on a limestone with fossil plants, including leaves of poplar, cinnamon, and pond-weed (*Potamogeton*), together with some insects; while in the bed No. 4, below, is a

bituminous rock, in which the *Mastodon tapiroides*, a characteristic Upper Miocene quadruped, has been met with. The 5th bed, two or three inches thick, contains fossil fish, e.g., *Leuciscus* (roach), and the larvæ of dragon-flies, with plants such as the elm (*Ulmus*), and the aquatic Chara. Below this are other plant-beds; and then, in No. 9, the stone in which the great salamander (*Andrias Scheuchzeri*) and some fish were found. Below this, other strata occur with fish, tortoises, the great salamander before alluded to, freshwater mussels, and plants. In No. 16 the fossil fox of Œningen, *Galecynus Œningensis*, Owen, was obtained by Sir R. Murchison. To this succeed other beds with mammalia (*Lagomys*), reptiles (*Emys*), fish, and plants, such as walnut, maple, and poplar. In the 19th bed are numerous fish, insects, and plants, below which are marls of a blue indigo colour.

In the lower quarry eleven beds are mentioned, in which, as in the upper, both land and freshwater plants and many insects occur. In the 6th, reckoning from the top, many plants have been obtained, such as *Liquidambar*, *Cinnamomum*, *Podogonium*, and *Ulmus*, together with tortoises, besides the bones and teeth of a ruminant quadruped, named by H. von Meyer *Paleomeryx eminens*. No. 9 is called the insect bed, a layer only a few inches thick, which, when exposed to the frost, splits into leaves as thin as paper. In these thin laminæ plants such as *Liquidambar*, *Cinnamomum*, and *Glyptostrobus* occur, with innumerable insects in a wonderful state of preservation, usually found singly. Below this is an indigo-blue marl, like that at the bottom of the higher quarry, resting on yellow marl ascertained to be at least thirty feet thick.

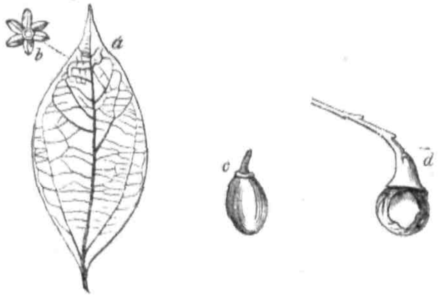
All the above fossil-bearing strata were evidently formed with extreme slowness. Although the fossiliferous beds are, in the aggregate, not more than a few yards in thickness, and have only been examined in the small area comprised in the two quarries just alluded to, they give us an insight into the state of animal and vegetable life in part of the Miocene period, such as no other region in the world has elsewhere supplied. In the year 1859, Prof. Heer had already determined no less than 475 species of plants and more than 800 insects from these Œningen beds. He supposes that a river entering a lake floated into it some of the leaves and land insects, together with the carcases of quadrupeds, among others a great Mastodon. Occasionally, during tempests, twigs and even boughs of trees with their leaves were torn off and carried for some distance so as to reach the lake. Springs, containing carbonate of lime, seem at some points to have supplied calcareous matter in solution,

giving origin locally to a kind of travertin, in which organic bodies sinking to the bottom became hermetically sealed up.

In his work entitled 'The Naturalist on the Amazons,' Mr. Bates mentions having observed on the Tapajos river in Brazil the dead or half-dead bodies of ants heaped up in a line an inch or two in height and breadth for miles along the beach.[1] I am also informed by the same naturalist that on the sandy shores of Lake Ega, on the Upper Amazons, he saw on several occasions sloping ridges of dead insects of all orders piled up on the margin of the lake. This sudden destruction of whole shoals of insects is caused, he says, by a sudden chill and squall occurring in the night over a wide expanse of water after a hot evening. The insects are tempted to fly by the sultry weather, the chill and storm overtake them, and they are cast into the water, the waves of which wash their bodies on to the lee-shore. Sand is also often thrown up at the same time, and some of the insects are thus buried a little above the water-line.

The laminæ of the Œningen beds which immediately succeed each other were not all formed, according to Prof. Heer, at the same season, for it can be shown that when some of them originated, certain plants were in flower, whereas, when the next of these layers was produced, the same plants had ripened

Fig. 143.



Cinnamomum polymorphum, Ad. Brong. Upper and Lower Miocene.

a. Leaf. *b*. Flower, nat. size. Heer, Pl. 93, fig. 28.
c. Ripe fruit of *Cinnamomum polymorphum*, fram Œningen. Heer, Pl. 94, fig. 14.
d. Fruit of recent *Cinnamomum camphorum* of Japan. Heer, Pl. 152, fig. 18.

their fruit. This inference is confirmed by independent proofs derived from insects. The principal insect-bed is rarely two inches thick, and is composed, says Heer, of about 250 leaf-like laminæ, some of which were deposited in the spring, when the

[1] Naturalist on the Amazons, 1863, vol. ii. p. 85.

Cinnamomum polymorphum (fig. 143) was in flower; others in summer, when winged ants were numerous, and when the poplar and willow had matured their seed; others, again, in autumn, when the same *Cinnamomum polymorphum* (fig. 143) was in fruit, as well as the liquidambar, oak, clematis, and many other plants. The ancient lake seems to have had a belt of poplars and willows round its borders, countless leaves of which were imbedded in mud, and together with them at some points a species of reed, *Arundo*, which was very common.

One of the most characteristic shrubs is a leguminous and papillionaceous plant of an extinct genus, called by Heer *Podogonium*, of which two species are known. Entire twigs have been found with flowers, and always without leaves, as the flowers evidently came out, as in the poplar and willow tribe, before any leaves made their appearance. Other specimens have been obtained with ripe fruits accompanied by leaves, which resemble those of the tamarind, to which it was evidently allied, being of the family Cæsalpinæ, now proper to warmer regions.

The Miocene flora of Œningen is peculiarly important, in consequence of the number of genera of which not merely the leaves but, as in the case of the *Podogonium* just mentioned, the fruit also and even the flower are known. Thus there are

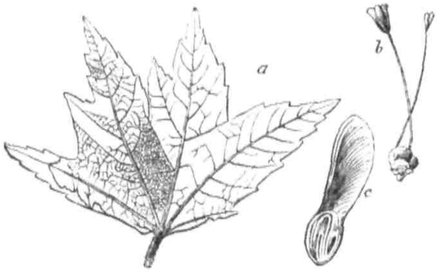
Fig. 144.

Acer trilobatum, normal form. Heer, Flora Tert. Helv., Pl. 114, fig. 2. Size ½ diam.
(Part only of the long stalk of the original fossil specimen is here given.)
Upper Miocene, Œningen; also found in the Oligocene of Switzerland.

nineteen species of maple, ten of which have already been found with fruit. Although in no one region of the globe do so many maples now flourish, we need not suspect Prof. Heer

of having made too many species in this genus when we consider the manner in which he has dealt with one of them, *Acer trilobatum* (figs. 144, 145). Of this plant the number of marked varieties figured and named is very great, and no less than three of them had been considered as distinct species by other

Fig. 145.



Acer trilobatum.

a. Abnormal variety of leaf. Heer, Pl. 110, fig. 16.
b. Flower and bracts, normal form. Heer, Pl. 111, fig. 21.
c. Half a seed vessel. Heer, Pl. 111, fig. 5.

botanists, while six of the others might have laid claim, with nearly equal propriety, to a like distinction. The common form, called *Acer trilobatum*, fig. 144, may be taken as a normal representative of the Œningen fossil, and fig. 145 as one of the most divergent varieties, having almost four lobes in the leaf instread of three.

Fig. 146.

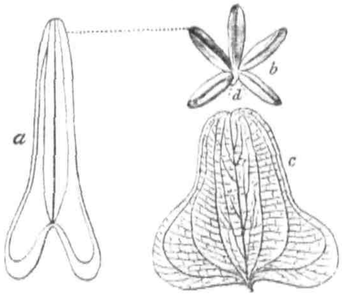
Platanus aceroides, Göpp.
Heer. Pl. 88, figs. 5–8.
Size ⅔ diam. Upper Miocene, Œningen.

a. Leaf.
b. The core of a bundle of pericarps.
c. Single fruit or pericarp, nat. size.

Among the conspicuous genera which abounded in the Miocene period in Europe is the plane-tree, *Platanus*, the fossil species being considered by Heer to come nearer to the American *P. occidentalis* than to *P. orientalis* of Greece and Asia Minor. In some of the fossil specimens the male flowers are preserved. Among other points of resemblance with the living plane-trees, as we see them in the parks and squares of London, fossil fragments of the trunk are met with, having pieces of their bark peeling off.

The vine of Œningen, *Vitis teutonica*, Ad. Brong., is of a North American type. Both the leaves and seeds have been found at Œningen, and bunches of compressed grapes of the same species have been met with in the brown coal of Wetter-

Fig. 147.



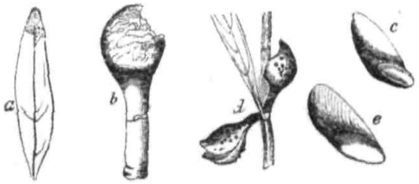
Similax sagittifera. Heer, Pl. 30, fig. 7. Size, ½ diameter.

Leaf. *b.* Flower magnified, one of the six petals wanting at *d.* Upper Miocene, Œningen. *c.* *Smilax obtusifolia*. Heer, Pl. 30, fig. 9; nat. size. Upper Miocene, Œningen.

avia in Germany. No less than eight species of *Smilax*, a monocotyledonous genus, occur at Œningen and in other Miocene localities, the flowers of some of them, as well as the leaves, being preserved, as in the case of the very common fossil, *Smilax sagittifera* (fig. 147, *a*).

Leaves of plants supposed to belong to the order Proteaceæ have been obtained partly from Œningen and partly from the

Fig. 148.



Fruit of the fossil and recent species of Hakea, a genus of Proteaceæ.

a. Leaf of Fossil species. *Hakea salicina*. Upper Miocene, Œningen; Heer, Pl. 97, fig. 29, ⅓ diam. *b.* Impression of woody fruit of same, showing thick stalk, ⅔ diam. *c.* Seed of same; natural size. *d.* Fruit of living Australian species, *Hakea saligna*, R. Brown, ½ diam. *e.* Seed of same; natural size.

lacustrine formation of the same age at Locle in the Jura. They have been referred to the genera *Banksia*, *Grevillea*, *Hakea*, and *Persoonia*. Of *Hakea* there is the impression of a

supposed seed-vessel, with its characteristic thick stalk and seeds; but as the fruit is without structure, and has not yet been found attached to the same stem as the leaf, the proof is incomplete.

To whatever family the foliage hitherto regarded as proteaceous, by many able palæontologists, may eventually be shown to belong, we must be careful not to question its affinity to that order of plants on those geographical considerations which have influenced some botanists. The nearest living Proteaceæ now flourish in Abyssinia in lat. 20° N., but the greatest number are confined to the Cape and Australia. The ancestors, however, of the Œningen fossils ought not to be looked for in such distant regions, but from that European land which in Oligocene times bore trees with similar foliage; and these had doubtless an Eocene source, for cones admitted by all botanists to be proteaceous have been met with in one division of that older Tertiary group, the London clay. The source of these last, again, must not be sought in the Antipodes, for in the white sands and laminated clays of cretaceous age at Aix-la-Chapelle, leaves like those of *Grevillea* and other proteaceous genera have been found in abundance, and, as we shall see, usually in a most perfect state of preservation. All geologists agree that the distribution of the cretaceous land and sea had scarcely any connection with the present geography of the globe.

In the same beds with the Proteaceæ, there occurs at Locle a fan-palm of the American type Sabal (for genus see fig. 154), a genus which ranges throughout the low country near the sea from the Carolinas to Florida and Louisiana. Among the Coniferæ of Upper Miocene age is found a deciduous cypress nearly allied to the *Taxodium distichum* of North America, and a *Glyptostrobus* (fig. 149), very like the Japanese *G. heterophyllus*, now common in our shrubberies.

Fig. 149.

Glyptostrobus Europæus. Branch with ripe fruit. Heer, Pl. 20, fig. 1. Upper Miocene, Œningen.

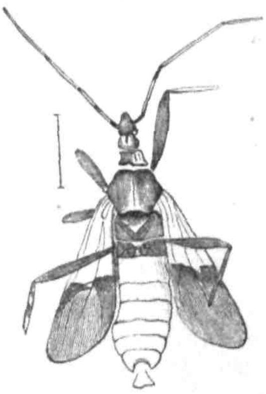
Before the appearance of Heer's work on the Miocene Flora of Switzerland, Unger and Göppert had already pointed out the large proportion of living North American genera which distinguished the vegetation of the Miocene period in Central Europe. Next in number, says Heer, to these American forms at Œningen the European genera preponderate, the Asiatic ranking in the third, the African in the fourth, and the Australian in the fifth degree. The American forms are more numerous than in the Italian Pliocene flora, and the whole vegetation indicates a warmer climate than the

Pliocene, though not so high a temperature as that of the older or Lower Miocene period (Oligocene).

The conclusions drawn from the insects are for the most part in perfect harmony with those derived from the plants, but they have a somewhat less tropical and less American aspect, the South European types being more numerous. On the whole, the insect fauna is richer than that now inhabiting any part of Europe. No less than 844 species are reckoned by Heer from the Œningen beds alone, the number of specimens which he has examined being 5,080. Nearly all the species belong to *existing genera. Almost all the living families of Coleoptera* are represented; but, as we might have anticipated from the preponderance of arborescent and ligneous plants, the wood-eating beetles play the most conspicuous part, the Buprestidæ and other long-horned beetles being particularly abundant.

The patterns and some remains of the colours both of *Coleoptera* and *Hemiptera* are preserved at Œningen; as, for example, in the drawing (fig. 150) of *Harpactor*, in which the antennæ, one of the eyes, and legs and wings are retained. The characters, indeed, of many of the insects are so well defined as to incline us to believe that, if this class of the invertebrata were not so rare and local, they might be more useful than even the plants and shells in settling disputed points in geological chronology.

Fig. 150.



Harpactor maculipes, Heer. Upper Miocene, Œningen.

Middle or Marine Molasse of Switzerland ('Helvetian').—It was before stated that the Miocene formation of Switzerland consisted of—1st, the upper freshwater molasse, comprising the lacustrine marls of Œningen; 2ndly, the marine molasse, corresponding in age to the faluns of Touraine; and 3rdly, the lower freshwater molasse. Some of the beds of the marine or middle series reach a height of 2,470 feet above the sea. A large number of the shells are common to the faluns of Touraine, the Vienna basin, and other Upper Miocene localities. The terrestrial plants play a subordinate part in the fossiliferous beds, yet more than ninety of them are enumerated by Heer as belonging to this falunian division, and of these more than half are common to the subjacent

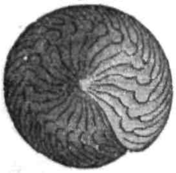
lower molasse, while a proportion of about 45 in 100 are common to the overlying Œningen flora ; 26 of the 92 species are peculiar.

A *Dryopithecus* has been found in the beds ; and in the marine part. *Pectunculus glycimeris* denotes a high Miocene horizon.

Miocene beds of the Vienna basin.—In South Germany the general resemblance of the shells of the Vienna tertiary basin to those of the faluns of Touraine has long been acknowledged. In the late Dr. Hörnes' excellent work on the fossil mollusca of that formation, we see accurate figures of many shells, clearly of the same species as those found in the falunian sands of Touraine.

According to Professor Suess, the most ancient and purely marine of the Miocene strata in this basin, consist of sands, conglomerates, limestones, and clays, and they are inclined inwards, or from the borders of the trough towards the centre, their outcropping edges rising much higher than the newer beds, whether Miocene or Pliocene, which overlie them, and which occupy a smaller area at an inferior elevation above the sea. Dr. Hörnes has described no less than 500 species of gasteropods, of which he identifies one-fifth with living species of the Mediterranean, Indian, or African seas, but the proportion of existing species among the lamellibranchiate bivalves exceeds this average. In the lowest marine beds of the Vienna basin the remains of several mammalia have been found, and among them a species of *Dinotherium*, a Mastodon of the *Trilophodon* division, a Rhinoceros (allied to *R. megarhinus*, Christol), also an animal of the hog tribe, *Listriodon*, Von Meyer, and a carnivorous animal of the canine family. The *Helix turonensis* (fig. 38, p. 32), the most common land shell of the French faluns, accompanies the above land animals.

Fig. 151.



Amphistegina Hauerina, D'Orb. Upper Miocene strata, Vienna ; mag. 10 diams.

M. Alcide d'Orbigny has shown that of the foraminifera of the Vienna basin the genus *Amphistegina* (fig. 151) is very characteristic, and is supposed by d'Archiac to take the same place among the Rhizopods of the Miocene era which the Nummulites occupy in the Eocene period.

The flora of the Vienna basin exhibits some species which have a general range through the whole Miocene period, such as *Cinnamomum polymorphum* (fig. 143), and *C. Scheuchzeri*, also *Planera Richardi*, Mich., *Liquidambar europæum* (fig. 137, p. 174), *Juglans bilinica*, *Cassia ambigua*, and *C. lignitum*. Among the plants common to the Miocene beds of Œningen in Switzerland are *Platanus aceroides* (fig. 146, p. 188), *Myrica vindobonensis*, and others.

There are two great divisions in the Miocene tertiaries of the great area called the Vienna basin. Sandstones, limestones, and clays, with *Cerithia*, and vast quantities of a few species of *Tapes*, *Mactra*, *Murex*, &c. Corals and Bryozoa are rare. This Sarmatian division covers a marine group with limestones crowded with corals—the Leithakalk, which enjoyed a subtropical climate.

The Miocene of the Mayence Basin.—This underlies the bone bed of Epplesheim (p. 175), and is fluviatile, estuarine, and terrestrial in its nature. The beds contain a fauna which differs from that of Epplesheim, none of the genera being identical—*Dinotherium*, *Palæomeryx*, *Microtherium*, *Hippotherium*. Amongst the shells are *Dreissenæ*, *Mytili*, *Litorinellæ*, &c., the whole having a very Pliocene appearance. But the presence of *Sabal* and *Cinnamomum* gives a more ancient facies.

The Miocene rests on a Cyrena marl of Oligocene age.

Miocene strata of Italy.—We are indebted to Signor Michelotti for a valuable work on the Miocene shells of Northern Italy. Those found in the hill called the Superga, near Turin, have long been known to correspond in age with the faluns of Touraine, and they contain so many species common to the Miocene strata of Bordeaux as to lead to the conclusion that there was a free communication between the northern part of the Mediterranean and the Bay of Biscay during the Miocene Period. In the hills of which the Superga forms part, these Tertiary strata pass down into the Oligocene.

The Miocene of the Western Territories of the United States.—The Miocene deposits are those of ancient lake basins on the flanks of the high central plateau of North America. The Miocene fauna is divisible into three groups, and it is probable that the lowest corresponds with the European Oligocene. But we give Professor Marsh's details without comment. The lowest Miocene is only found on the east of the Rocky Mountains, and is characterised by the peculiar mammals termed *Brontotheridæ*. These were perissodactyles with affinities with the Tapirs. *Brontotherium* was as large as an elephant; the limbs were short, tail long, and the nose was probably flexible. A pair of horn cores existed upon the maxillary bones in front of the orbits, and the brain cavity was small. *Mesohippus*, as large as a sheep, is a representative of the horse, and is a transitional form between the Eocene and late Pliocene *Equus*, the intermediate form being *Miohippus* of the Upper Miocene, and *Protohippus* of the Pliocene. *Dicerotherium*, allied to *Rhinoceros* and *Tapiravus*, existed. *Perchærus* and *Elotherum* were the great pigs of the day, and some equalled *Rhinoceros*

in dimensions. *Hyopotamus* was a crescent-toothed, even-toed creature. *Poebrotherium*, allied to the Camel, *Leptomeryx* to the Deer, occur; but the hollow-horned ruminants had not yet appeared, nor had the Proboscideans. Insectivora lived in those days, however. *Hyænodon* was a carnivore.

The Middle Miocene, on both sides of the Rocky Mountains, is characterised by ruminating pigs of the genera *Oreodon* and *Eporeodon*, which were larger than the Peccary. The *Leporidæ*, or Hare family, lived in considerable numbers; and other Rodentia of the Squirrel, Mouse, and Beaver families, were represented by genera now extinct. *Machairodus* occurs; and *Laopithecus*, one of the Monkey tribe, and of South American affinity. The Upper Miocene, which occurs in Oregon, is of great thickness, and the characteristic genus is *Miohippus*, already noticed. *Hyracodon*, *Dicerotherium*, and *Acerotherium* were Rhinocerotidea of the period, and *Chalicotherium* was a genus which is also found fossil in Europe and in the Himalayan area. Besides these forms, there were *Moropus*, a large Edentate, *Tinohyus*, an ally of the Peccary, and *Allomys*, related to the flying Squirrels.

Marine Miocene beds with Corals and abundant Echini occur in Corsica, Egypt, Asia Minor, and in Sind. In Sind are important marine strata, crowded with Corals and Echini, and which are distinct in their faunal facies from the underlying Oligocene strata. The Gaj or Miocene of Sind and Kach is covered by freshwater deposits of Pliocene or Siválik age.

The West Indian Islands contain a deep Marine Miocene; in Jamaica it is overlaid by an important white limestone of Pliocene age. The Australian Tertiary deposits come within the Miocene and Pliocene epochs.

CHAPTER XV.

OLIGOCENE.

The Oligocene of Beyrich includes the Lower Miocene and part of the Upper Eocene—The Oligocene of France—The relation of the Miocene to the Calcaire de la Beauce—The Grès de Fontainebleau—The Sables d'Etampes — The Gypseous Lacustrine series — Oligocene of Central France—Auvergne—Mammalia of the Limagne—Oligocene of Belgium—Oligocene or Lower Molasse of Switzerland—Conglomerates and Flora—Italian Oligocene—German Oligocene—Oligocene of England—Croatian, Viennese, and Indian Oligocene.

Oligocene strata.—Professor Beyrich has made known to us the existence of a long succession of marine strata in North Germany, which lead, by an almost gradual transition, from beds of Upper Miocene age to others of the age of the base of the Lower Miocene. Although some of the German lignites called Brown Coal belong to the upper parts of this series, the most important of them are of Lower Miocene date, as, for example, those of the Siebengebirge, near Bonn, which are associated with volcanic rocks. Professor Beyrich confines the term 'Miocene' to those strata which agree in age with the faluns of Touraine, and he has proposed the term 'Oligocene' for those older formations called Lower Miocene in former editions of this work, and much of the Upper Eocene also.

The Oligocene of France.—The marine faluns of the valley of the Loire have been already described as resting in some places on a freshwater tertiary limestone, fragments of which have been broken off and rolled on the shores and in the bed of the Miocene sea. Such pebbles are frequent at Pontlevoy on the Cher, with hollows drilled in them in which the perforating marine shells of the Falunian period still remain. Such a mode of superposition implies an interval of time between the origin of the freshwater limestone and its submergence beneath the waters of the Miocene sea. The limestone in question forms a part of the formation called the Calcaire de la Beauce, which constitutes a large tableland between the basins of the Loire and the Seine. It is associated with marls and other deposits, such as may have been formed in marshes and shallow lakes in the newest part of a great delta. Beds of flint, continuous or in nodules, accumulated in these lakes, and aquatic plants, called *Charæ*, left their stems and seed-vessels embedded both in the marl and flint, together with freshwater and land shells. Some of the siliceous rocks of this formation

are used extensively for millstones. The flat summits or platforms of the hills round Paris, and large areas in the forests of Fontainebleau, as well as the Plateau de la Beauce, already alluded to, are chiefly composed of these freshwater strata. Next to these, in the descending order, are marine sands and sandstone, commonly called the Grès de Fontainebleau, from which have been obtained a considerable number of shells and some marine fossils of the same kinds as those of the faluns—*Cytherea incrassata* and *Lucina Heberti*, for instance.

Next in succession, forming the Middle Oligocene, are the Sables d'Etampes with ferruginous sands at Paris, resting on marls with *Ostrea cyathula* and *Corbula sub-pisum*. These cover the Calcaire de Brie which overlies clay and green marl with *Cerithium plicatum* and *Cyrena convexa*.

The Lower Oligocene forms part of the Gypseous series of Montmartre, and is restricted to the Lacustrine group.

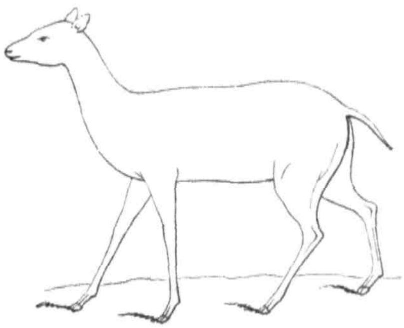
Lacustrine gypseous series of Montmartre.—These strata, commencing with white marls and blue marls at the top, and having the important gypsum beds below, are most largely developed in the central parts of the Paris Basin, and, among other places, in the hill of Montmartre, the fossils of which were first studied by Cuvier.

The gypsum quarried there for the manufacture of plaster of Paris, occurs as a granular crystalline rock, and, together with the associated marls, contains land and fluviatile shells, and the bones and skeletons of birds and quadrupeds. Several land-plants are also met with, among which are fine specimens of the fan-palm or palmetto tribe (*Flabellaria*). The remains also of freshwater fish, and of crocodiles and other reptiles, occur in the gypsum. The skeletons of mammalia are usually isolated, often entire, the most delicate extremities being preserved; as if the carcases, clothed with their flesh and skin, had been floated down soon after death, and while they were still swollen by the gases generated by their first decomposition. The few accompanying shells are of those light kinds which frequently float on the surface of rivers, together with wood.

In this formation the relics of about fifty species of quadrupeds, including the genera *Palæotherium*, *Anoplotherium*, and others, have been found, all extinct, and nearly four-fifths of them belonging to the Perissodactyle or odd-toed division of the order *Ungulata*, which now contains only four living genera—namely, rhinoceros, tapir, horse, and hyrax. The *Anoplotheridæ* form a family intermediate between pachyderms and ruminants, and was of the even-toed group of Ungulates. One of the three divisions of this family is that of the *Xiphodontidæ*.

Their forms were slender and elegant, and one, named *Xiphodon gracile* (fig. 152), was about the size of the Chamois; and Cuvier inferred from the skeleton that it was as light, graceful, and

Fig. 152.



Xiphodon gracile, Cuvier. Restored outline.

agile as the Chevrotain. With these Ungulata were associated a few carnivorous animals, among which were *Hyænodon dasyuroides*; a species of dog, *Canis Parisiensis*; and a weasel, *Cynodon Parisiensis*. Of the *Rodentia* were found a squirrel; of the *Cheiroptera*, a bat; while the family *Didelphidæ* of the *Marsupialia*, now confined to America, are represented by a true Opossum (*Didelphys*).

Of birds, about 17 species have been discovered, five of which are still undetermined. The skeletons of some are entire, but none are referable to existing species.[1] Crocodiles, and tortoises of the genera *Emys* and *Trionyx* were found.

Fossil footprints.—Amongst the many interesting remains of this series are footprints of animals, which occur at six different levels.[2] I visited the quarries, soon after the discovery was made known, with M. Desnoyers, who also showed me large slabs in the Museum at Paris, where, on the upper planes of stratification, the indented footmarks were seen, while corresponding casts in relief appeared on the lower surfaces of the strata of gypsum which were immediately superimposed. A thin film of marl, which, before it was dried and condensed by pressure, must have represented a much thicker layer of soft mud, intervened between the beds of solid gypsum. On this mud the animals had trodden, and made impressions which had

[1] Cuvier, Oss. Foss. tom. iii. p. 255.

[2] Sur des empreintes de pas d'Animaux, par M. J. Desnoyers. Compte rendu de l'Institut, 1859.

penetrated to the gypseous mass below, then evidently unconsolidated. Tracks of the *Anoplotherium*, with its bisulcate hoof, and the trilobed footprints of *Palæotherium*, were seen of different sizes, corresponding to those of several species of these genera which Cuvier had reconstructed, while in the same beds were footmarks of carnivorous mammalia. The tracks also of fluviatile, lacustrine, and terrestial tortoises (*Emys*, *Trionyx*, &c,) were discovered ; also those of crocodiles, iguanas, geckos, and great batrachians ; and the footprints of a huge bird, apparently a wader like a Rail, called *Gypsornis*. There were likewise impressions of the feet of other creatures, some of them clearly distinguishable from any of the extinct types of mammalia, of which the bones have been found in the Paris gypsum. The whole assemblage, says Desnoyers, indicates the shores of a lake, or several small lakes communicating with each other, on the borders of which many species of Ungulates wandered, and beasts of prey which occasionally devoured them. The toothmarks of these last had been detected on the bones and skulls of *Palæotheria* entombed in the gypsum by palæontologists long before.

The following is a list of the more important genera of the mammalia of the Oligocene of France :—Upper Oligocene : *Tapir*, *Palæochærus*, *Plesiosorex*, *Mysarachne*, *Lutrictis*, *Tetracus*, *Hyopotamus*, *Anthracotherium*, Shrew, Mole, Musk-rat. Middle Oligocene : *Hyarachius*, *Entelodon*, *Anthracotherium*, *Dacrytherium*, *Chalicotherium*, *Tragulohyus*, *Dremotherium*, *Canis*, *Plesictis*, *Plesiogale*, *Ælurogale*, *Rhinolophus*, *Necrolemur*, and Civet and Marten. The Lower Oligocene contains *Chæropotamus*, *Tapirulus*, *Anoplotherium*, *Cainotherium*, *Cebochærus*, *Xiphodon*, *Amphymeryx*, *Plesiarctomys*, *Hyænodon*, *Adapis*, *Didelphys*.

The genera *Anoplotherium* and *Palæotherium* cease with the Middle Oligocene. *Adapis* and *Macrolemur* are Lemurines, and represent the Quadrumania ; true Apes and Monkeys had not appeared.

Oligocene of Central France.—Lacustrine strata, belonging, for the most part, to the same age as the Calcaire de la Beauce, are again met with further south, in Auvergne, Cantal, and Velay. They appear to be the monuments of ancient lakes, which, like some of those now existing in Switzerland, once occupied the depressions in a mountainous region, and have been each fed by one or more rivers and torrents.

The study of these regions possesses a peculiar interest, for we are presented in Auvergne with the evidence of a series of events of astonishing magnitude and grandeur, by which the

original form and features of the country have been greatly changed, yet never so far obliterated but that they may still, in part at least, be restored in imagination. Great lakes have disappeared—lofty volcanic mountains have been formed by the reiterated emission of lava, preceded and followed by showers of sand and scoriæ—deep valleys have been subsequently furrowed out through masses of lacustrine and volcanic origin—at a still later date, new cones have been thrown up in these valleys—new lakes have been formed by the damming up of rivers—and more than one assemblage of quadrupeds, birds, and plants, Eocene, Oligocene, Miocene, and Pliocene, have followed in succession. Yet the region has preserved from first to last its geographical identity; and we can still recall to our thoughts its external condition and physical structure, before these wonderful vicissitudes began, or while a part only of the whole had been completed. There was first a period when the spacious lakes, of which we still may trace the boundaries, lay at the foot of mountains of moderate elevation, unbroken by the bold peaks and precipices of Mont Dore, and unadorned by the picturesque outline of the Puy-de-Dôme, or of the volcanic cones and craters now covering the granitic platform. During this earlier scene of repose, deltas were slowly formed; beds of marl and sand, several hundred feet thick, deposited; siliceous and calcareous rocks precipitated from the waters of mineral springs; shells and insects embedded together with the remains of the crocodile and tortoise, the eggs and bones of water-birds, and the skeletons of quadrupeds, most of them of genera and species characteristic of the period. To this tranquil condition of the surface succeeded the era of volcanic eruptions, when the lakes were drained, and when the fertility of the district was probably enhanced by the igneous matter ejected from below, and poured down upon the more sterile granite. During these eruptions, which appear to have taken place towards the close of the Miocene epoch, and which continued during the Pliocene, various assemblages of quadrupeds successively inhabited the district, amongst which are found the genera *Mastodon*, *Rhinoceros*, *Elephas*, *Tapir*, *Hippopotamus*, together with the ox, various kinds of deer, the bear, the hyæna, and many beasts of prey which ranged the forest or pastured on the plain, and were occasionally overtaken by a fall of burning cinders, or buried in flows of mud such as accompany volcanic eruptions. Lastly, these quadrupeds became extinct, and gave place in their turn to the species now existing. There are no signs, during the whole time required for this series of events, of the sea having intervened, nor of any denudation which may not have

been accomplished by currents in the different lakes, or by rivers and floods accompanying repeated earthquakes, or subterranean movements, during which the levels of the district have in some places been materially modified, and perhaps the whole upraised relatively to the surrounding parts of France.

Auvergne.—The most northern of the freshwater groups is situated in the valley plain of the Allier, which lies within the department of the Puy-de-Dôme, being the tract which went formerly by the name of the Limagne d'Auvergne. The principal divisions into which the lacustrine series may be separated are the following:—1st, Sandstone, grit, and conglomerate, including red marl and red sandstone; 2ndly, Green and white foliated marls; 3rdly, Limestone, or travertin, often oolitic in structure; 4thly, Gypseous marls. They rest on granite.

It seems that, when the ancient lake of the Limagne first began to be filled with sediment, no volcanic action had yet produced lava and scoriæ on any part of the surface of Auvergne. No pebbles, therefore, of lava were transported into the lake—no fragments of volcanic rocks embedded in the conglomerate. But at a later period, when a considerable thickness of sandstone and marl had accumulated, eruptions broke out, and lava and tuff were deposited, at some spots, alternately with the lacustrine strata. It is not improbable that both cold and hot springs, holding different mineral ingredients in solution, became more numerous during the successive convulsions attending this development of volcanic agency, and thus deposits of carbonate and sulphate of lime, silica, and other minerals were produced. Hence these minerals predominate in the uppermost strata. The subterranean movements may then have continued until they altered the relative levels of the country, and caused the waters of the lakes to be drained off, and the farther accumulation of regular freshwater strata to cease.

Oligocene mammalia of the Limagne.—It is scarcely possible to determine the age of the oldest part of the freshwater series of the Limagne, large masses both of the sandy and marly strata being devoid of fossils. Some of the lowest beds may be of Upper Eocene date, although, according to M. Pomel, only one bone of a *Palæotherium* has been discovered in Auvergne. But in Vélay, in strata containing some species of fossil mammalia common to the Limagne, no less than four species of *Palæotherium* have been found by M. Aymard, and one of these is generally supposed to be identical with *Palæotherium magnum*, an undoubted Upper Eocene fossil, of the Paris gypsum, the other three being peculiar to the Limagne.

Not a few of the other mammalia of the Limagne belong

undoubtedly to genera and species elsewhere proper to the Oligocene. Thus, for example, the *Cainotherium* of Bravard, a genus not far removed from the *Anoplotherium*, is represented by several species, one of which agrees with *Microtherium Renggeri* of the Mayence basin. In like manner, the *Amphitragulus elegans* of Pomel, an Auvergne fossil, is the same as *Dorcatherium nanum* from Weissenau, near Mayence. A small species also of rodent, of the genus *Titanomys* of Meyer, is common to the Oligocene of Mayence and the Limagne d'Auvergne; and there are many other points of agreement which the discordance of nomenclature tends to conceal. A remarkable carnivorous genus, the *Hyænodon* of Laizer, is represented by more than one species. The same genus has also been found in the marls of Hordwell Cliff, Hampshire, just below the level of the Bembridge Limestone, and therefore in a formation older than the gypsum of Paris. Several species of opossum (*Didelphis*) are met with in the same strata of the Limagne. The total number of mammalia enumerated by M. Pomel as appertaining to the Oligocene fauna of the Limagne and Vélay, falls little short of a hundred, and with them are associated some large crocodiles and tortoises, and some Ophidian and Batrachian reptiles. The birds of the Limagne and those of the Mayence basin are, according to Mr. Milne Edwards, almost identical. Among those of the Limagne are extinct species of duck, stork, and many of the swallow tribe; also several kinds of pheasants and species of Trogon and parrot, birds which are now confined to Asia and the tropics of both hemispheres.

Oligocene of Belgium: Tongrian and Rupelian.—These strata are marine and fluvio-marine, and are well developed near Tongres, in Limbourg. Great discrepancy of opinion regarding the position of certain strata of the Belgian area, beneath the Crag, has been produced by careless determination of the species of fossils, and by the difficulty of obtaining sections. Thus the Bolderberg strata of sand and gravel near Hasselt have been placed in the Upper Miocene on the belief that *Oliva Dufresnii* is a common shell there. But this form really belongs to a higher horizon, to the Antwerp Crag (p. 168), and is not mentioned as a fossil from the Bolderberg by Mourlon in his admirable lists. The shell is really *Oliva flammulata* of Lamarck, and comes from the lowest division of the Antwerpian series. There is no true Miocene nor Upper Oligocene in Belgium.

Recent investigations and the examination of sections at Kerniel, north-east of Looz, show that the Bolderberg sands

overlie the Boom clay (Argile de Boom), and are not quite at the top of the Oligocene, but at the top of the middle division of it. The Middle Oligocene, or Rupelian, includes the Marine series of the Bolderberg and Argile de Boom, so called from the villages of Boom and Rupelmonde, south of Antwerp, which cover a fluvio-marine group with *Cerithium* and *Pectunculus* and the Argile de Henis. The lower division, or Tongrian, includes the sands in the neighbourhood of Tongres, and is the continuation of the Lower Oligocene, or Egeln series of Germany, and corresponds with the upper part of the Gypseous series of Montmartre, and with the Headon series of England.

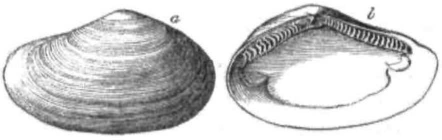
Having this base, it is not difficult to comprehend the extension of the overlying Middle Oligocene. The Argile de Henis is equivalent to the green clays with *Cyrena* of the Mayence basin, with the deposits at Bembridge in the Isle of Wight, and with the upper Montmartre green marls which overlie the Gypseous series.

The deposits of Klein-Spauwen, a village to the west of Maestricht, which are above the Henis clay, are of the same age as the Grès de Fontainebleau and as the Hempstead series.

The Upper, or Marine division of the Middle Oligocene of Belgium, with the Argile de Boom and the Bolderberg sands, is the equivalent of the Septarien-Thon of Germany and the Upper Lacustrine series of the Calcaire de la Beauce of France.

Halitherium is found in the Middle Oligocene, and the teeth of *Carcharodon*, *Myliobates*, *Lamna*, and other sharks are common to it and the Lower Oligocene, or Tongrian. Many small crustacea are found in the Middle series, and a fossil lobster, *Homarus*. The *Nautilus ziczac* (*Atruria*) is in the upper deposit, and many Gasteropoda are found. *Pleurotoma Selysi*, De Kon

Fig. 153.



Leda Deshayesiana, Duch., nat. size.

= *P. Wethereli*, Edw., *P. regularis* = *P. Belgica*, Gold., and *P. sub-denticulata* run through the whole series. *Fusus elongatus*, *Cassidaria nodosa*, *Murex Deshayesi*, *Cancellaria evulsa*, and *Corbula sub-pisum*, D'Orb, do the same. *Terebratula grandis* and *Terebratulina Nysti* are Tongrian, but *Ostrea gigantea* and *Pecten Hoeninghausi* are of the Middle Oligocene. The *Cyrena*

semistriata and other *Cyrenæ* are Middle Oligocene, as is also *Panopæa Heberti.* On the other hand, *Fusus* comes in high up in the Middle series. *Leda Deshayesiana* (fig. 153) is common to the Lower and Middle series, and *Cerithium plicatum* is in the Middle series.

Lower Molasse of Switzerland (Aquitanian).—Nearly the whole of this Lower Molasse is freshwater ; yet some of the inferior beds contain a mixture of marine and fluviatile shells, the *Cerithium plicatum*, a well-known Oligocene fossil, being one of the marine species. Notwithstanding, therefore, that some of these Oligocene strata consist of old shingle beds several thousand feet in thickness, as in the Rigi near Lucerne, and in the Speer near Wesen, forming mountains 5,000 and 7,000 feet above the sea, the deposition of the whole series must have begun at or below the sea-level.

The conglomerates, as might be expected, are often very unequal in thickness in closely adjoining districts ; since in a littoral formation accumulations of pebbles would swell out in certain places where rivers entered the sea, and would thin out to comparatively small dimensions where no streams, or only small ones, came down to the coast. For ages, in spite of a gradual depression of the land and adjacent sea-bottom, the rivers continued to cover the sinking area with their deltas ; until finally, the subsidence being in excess, the sea of the Middle Molasse gained upon the land, and marine beds were thrown down over the dense mass of freshwater and brackish-water deposit, called the Lower Molasse, which had previously accumulated.

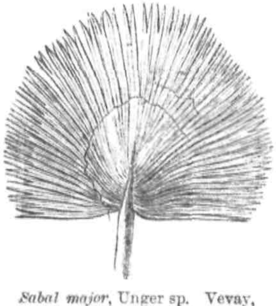
Flora of the Lower Molasse.—In part of the Swiss Molasse which belongs exclusively to the Oligocene Period, the number of plants has been estimated at more than 500 species, somewhat exceeding those which were before enumerated as occurring in the two upper divisions. The series may best be studied on the northern borders of the Lake of Geneva between Lausanne and Vevay, where the contiguous villages of Monod and Rivaz are situated. The strata there, which I have myself examined, consist of alternations of conglomerate, sandstone, and finely laminated marls with fossil plants. A small stream falls in a succession of cascades over the harder beds of pudding-stone, which resist, while the sandstone and plant-bearing shales and marls give way. From the latter no less than 193 species of plants have been obtained by the exertions of MM. Heer and Gaudin, and they are considered to afford a true type of the vegetation of the age—a vegetation departing farther in its character from that now flourishing in Europe than any of the

higher members of the series before alluded to, and yet displaying so much affinity to the flora of Œningen as to make it natural for the botanist to refer the whole to one and the same Miocene period. There are, indeed, no less than 81 species of these older plants which pass up into the flora of Œningen.

The proofs of a warmer climate and the excess of arborescent over herbaceous plants and of evergreen trees over deciduous species, are characters common to the whole flora, but which are intensified as we descend to the inferior deposits.

Nearly all the plants at Monod are contained in three layers of marl separated by two of soft sandstone. One bed is filled with large leaves of a species of fig (*Ficus populina*), and of a hornbeam (*Carpinus grandis*), the strength of the wind having probably been great when they were blown into the lake; whereas another contiguous layer contains almost exclusively smaller leaves, indicating, apparently, a diminished strength in the wind. Some of the upper beds at Monod abound in leaves of Proteaceæ, Cyperaceæ, and ferns, while in some of the lower ones *Sequoia*, *Cinnamomum*, and *Sparganium* are common. A large palm tree was found unaccompanied by other fossils, and near Vevay, in the same series, the leaves of a fan-palm of the genus *Sabal* (fig. 154), a genus now proper to North America, were obtained.

Fig. 154.



Sabal major, Unger sp. Vevay, Oligocene. (Heer, Pl. 41.)

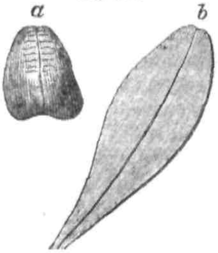
Among other genera of the same class is *Flabellaria* occurring near Lausanne, and *Phœnicites* which is allied to the modern Date palm. When these plants flourished, the climate must have been much hotter than now. The Alps were a low range, and the Palms now found fossil in strata elevated 2,000 feet above the sea, grew nearly at the sea-level, as is demonstrated by the brackish-water character of some of the beds into which they were carried by winds and rivers from the adjoining coast.

Proteaceæ are found, and now the Proteas and other plants of this family flourish at the Cape of Good Hope; while the Banksias, and a set of genera distinct from those of Africa, grow most luxuriantly in the southern and temperate parts of Australia.

It is a known fact that among the living Proteaceæ the cones are very firmly attached to the branches, so that the seeds drop

out, without the cone itself falling to the ground; and this may perhaps be the reason why, in some instances in which fossil seeds have been found, no traces of the cone have been observed.

Fig. 155.



a. Fruit of a fossil Banksia.
b. Leaf of *Banksia Deekiana*.

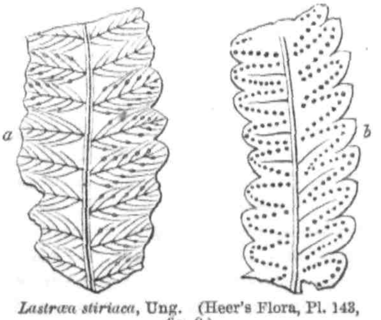
Fig. 156.

Sequoia Langsdorfii. Ad. Brong, ⅓ natural size. Rivaz, near Lausanne. (Heer, Pl. 21, fig. 4.) Oligocene, Miocene and Lower Pliocene, Val d'Arno.

a. Branch with leaves. *b*. Young cone.

Among the Coniferæ the *Sequoia* (fig. 156) is common at Rivaz, and is one of the most universal plants in the Oligocene of Switzerland.

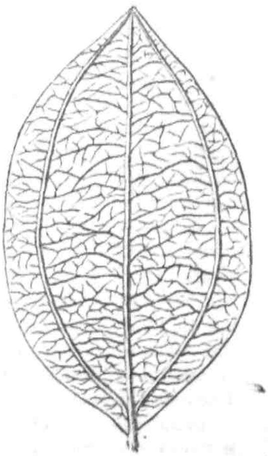
Fig. 157.



Lastræa stiriaca, Ung. (Heer's Flora, Pl. 143, fig. 8.)
Natural size. Oligocene and Miocene, Switzerland.

a. Specimen from Monod, showing the position of the sori on the middle of the tertiary nerves.
b. More common appearance, where the sori remain and the nerves are obliterated.

Fig. 158.



Cinnamomum Rossmässleri, Heer. *Daphnogene cinnamomifolia*, Unger. Oligocene and Miocene, Switzerland and Germany.

Lastræa stiriaca, Unger, has a wide range in the Tertiary period from strata of the age of Œningen to the lowest part of

the Swiss Molasse. In some specimens, as shown in fig. 157, the fructification is distinctly seen.

Among the laurels several species of *Cinnamomum* are very conspicuous. Besides *C. polymorphum*, before figured, fig. 143, another species also ranges from the Lower to the Upper Molasse of Switzerland, and is very characteristic of different deposits of Brown Coal in Germany. It has been called *Cinnamomum Rossmässleri* by Heer. (See fig. 158.) The leaves are easily recognised from having two side veins which run up uninterruptedly to their point.

American character of the flora.—If we consider not merely the number of species but those plants which constitute the mass of the Oligocene vegetation, we find the European part of the fossil flora very much less prominent than in the Œningen beds, while the foreground is occupied by American forms, by evergreen oaks, maples, poplars, planes, *Liquidambar*, *Robinia*, *Sequoia*, *Taxodium*, and ternate-leaved pines. There is also a much greater fusion of the characters now belonging to distinct botanical provinces, than in the Miocene flora, and we shall find this fusion still more strikingly exemplified as we go back to the antecedent Eocene and Cretaceous periods.

Professor Heer has advocated the doctrine, first advanced by Unger to explain the large number of American genera in this flora in Europe, that the present basin of the Atlantic was occupied by land over which the Miocene flora could pass freely. But other able botanists have shown that it is far more probable that the American plants came from the east and not from the west, and, instead of reaching Europe by the shortest route over an imaginary Atlantis, migrated in an opposite direction, crossing the whole of Asia.

Oligocene of Italy.—In the hills of which the Superga forms a part (see p. 193) there is a great series of Tertiary strata which pass downwards into the Oligocene. Even in the Superga itself there are some fossil plants which, according to Heer, have never been found in Switzerland so high as the marine Molasse, such as *Banksia longifolia* and *Carpinus grandis*. In several parts of the Ligurian Apennines, as at Dégo and Carcare, the Oligocene appears, containing some Nummulites, and at Cadibona, north of Savona, freshwater strata of the same age occur, with dense beds of lignite enclosing remains of the *Anthracotherium magnum* and *A. minimum*, besides other mammalia enumerated by Gastaldi. In these beds a great number of the Oligocene plants of Switzerland have been discovered.

The Marine Oligocene is of great importance, and contains but

few Nummulites, and a most interesting reef-building coral fauna.

Oligocene of Germany.—Oligocene beds of marine and freshwater kinds occupy depressions and detached areas which present very distinct faunas and floras. The succession of strata below and above is broken, and the Miocene and Eocene are absent. The upper deposits are Brown Coals, found in the Lower Rhine district, and the flora contains the genera *Acer*, *Cinnamomum*, *Juglans*, *Nyssa*, *Pinites*, *Quercus*, having a subtropical American facies. Some marine beds contain *Terebratula grandis*.

The Middle Oligocene is the Septarien-Thon, with *Leda Deshayesiana*, and in some places, plants are found forming local Brown Coals. The Lower Oligocene is marine above. The marine beds of Egeln, with corals and mollusca—these cover an amber-bearing glauconitic sand with insects, and at the base of all, are conglomerates and clays and pitch-coal—the Lower Brown Coal series. The flora is largely composed of Conifers, and Oak, Laurel, *Magnolia*, *Dryandroides*, *Ficus*, and *Sabal*, *Flabellaria*, Palms. The facies is sub-tropical, North American, with some Indian and Australian types.

Mayence basin.—An elaborate description has been published by Dr. F. Sandberger of the Mayence tertiary area, which occupies a tract from five to twelve miles in breadth, extending for a great distance along the left bank of the Rhine from Mayence to the neighbourhood of Mannheim, and which is also found to the east, north, and south-west of Frankfort. M. de Koninck, of Liège, first pointed out to me that the purely marine portion of the deposit contained many species of shells common to the Klein-Spauwen beds, and to the clay of Rupelmonde, near Antwerp. Among them he mentioned *Cassidaria depressa*, *Tritonium argutum*, Brander (*T. flandricum*, De Koninck), *Tornatella simulata*, *Aporrhais Sowerbyi*, *Leda Deshayesiana* (fig. 153), *Corbula sub-pisum*, and others.

The deposits underlie the sandstones with leaves and *Cerithium* limestones of the Miocene (p. 193), and may be divided into three groups. The upper is a Cyrena marl with *Cyrena semistriata* and *Cerithium plicatum*; the middle is a clay with *Leda Deshayesiana*; and the lowest is a marine sand (of Weinheim).

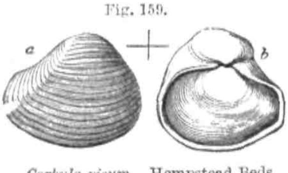
Oligocene of England.—We have already stated that Miocene sedimentary formations do not exist in the British Islands; but lower strata, now recognised as the equivalents of the Oligocene series of the Continent, are known in Hampshire and in the Isle of Wight. So far as is known, there is little or

no unconformity between these strata and the underlying true Eocene deposits. They have been termed the Fluvio-Marine series by Forbes.

An important marine deposit, found in sinking wells and making railway cuttings in the district of the New Forest, in Hampshire, at Brockenhurst and other places, is seen in the Isle of Wight, in the Headon beds, and the fossils contained have enabled palæontologists to correlate it with continental strata. The following is the succession in the Isle of Wight.

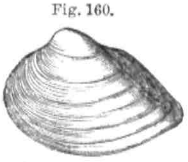
Hempstead Beds.—Of these the uppermost or Corbula beds consist of marine sands and clays, and contain *Voluta Rathieri*,

Fig. 159.



Corbula pisum. Hempstead Beds, Isle of Wight.

Fig. 160.



Cyrena semistriata, ½. Hempstead Beds.

a characteristic Oligocene shell; *Corbula pisum* (fig. 159), a species common to the Upper Eocene clay of Barton; *Cyrena semistriata* (fig. 160), several *Cerithia*, and other shells peculiar to this series.

Next below are freshwater and estuary marls and carbonaceous clays, in the brackish-water portion

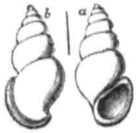
Fig. 161.

Cerithium plicatum, Lam., nat. size. Hempstead.

Fig. 162.

Cerithium elegans, nat. size, Hempstead.

Fig. 163.



Rissoa Chastelii, Nyst. Sp. Hempstead, Isle of Wight.

Fig. 164.

Paludina lenta. ½. Hempstead Beds.

of which are found abundantly *Cerithium plicatum*, Lam. (fig. 161), *C. elegans* (fig. 162), and *C. tricinctum*; also *Rissoa Chastelii* (fig. 163), a very common Klein-Spauwen shell, which occurs in each of the four subdivisions of the Hempstead series down to its base, where it passes into the Bembridge beds. In the freshwater portion of the same beds *Paludina lenta* (fig. 164) occurs; a shell identified by some conchologists with a species

now living, *P. unicolor*; also several species of *Limnæa*, *Planorbis*, and *Unio*.

The next series, or middle freshwater and estuary marls, are distinguished by the presence of *Melania fasciata*, *Paludina lenta*, and clays with *Cypris*; the lowest bed contains *Cyrena semistriata* (fig. 160), mingled with *Cerithia* and a *Panopæa*.

The lower freshwater and estuary marls contain *Melania costata*, Sow., *Melanopsis*, &c. The bottom bed is carbonaceous, and called the 'Black band,' in which *Rissoa Chastelii* (fig. 163), before alluded to, is common. This bed contains a mixture of Hempstead shells with those of the underlying Bembridge series. The mammalia, among which is *Hyopotamus bovinus*, differ, so far as they are known, from those of the Bembridge beds. The *Hyopotamus* belongs to the hog tribe, or the same family as the *Anthracotherium*, of which last, seven species, varying in size from the hippopotamus to the wild boar, have been found in Italy and other parts of Europe associated with the lignites of the Oligocene period.

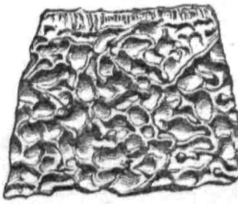
The seed-vessels of *Chara medicaginula*, Brong., and *C. helicteres* are characteristic of the Hempstead beds generally.

Bembridge series.—These beds are about 120 feet thick, and lie immediately under the Hempstead beds near Yarmouth, in the Isle of Wight. They consist of marls, clays, and limestones of freshwater, brackish, and marine origin. Some of the most abundant shells, as *Cyrena semistriata* var., and *Paludina lenta* (fig. 164), are common to this and to the overlying Hempstead series; but the majority of the species are distinct. The

Fig. 165.

Melania turritissima, Forbes. Bembridge.

Fig. 166.



Fragment of Carapace of *Trionyx*. Bembridge Beds, Isle of Wight.

following are the subdivisions described by the late Professor Forbes:—

a. Upper marls, distinguished by the abundance of *Melania turritissima*, Forbes (fig. 165).

b. Lower marls, characterised by *Cerithium mutabile*, *Cyrena pulchra*, &c., and by the remains of *Trionyx* (see fig. 166).

c. Green marls, often abounding in a peculiar species of oyster, and accompanied by *Cerithium*, *Mytilus*, *Arca*, *Nucula*, &c.

d. Bembridge limestones, compact cream-coloured limestones alternating with shales and marls, in all of which land-shells are

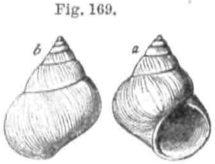
Fig. 167.

Bulimus ellipticus, Sow. Bembridge Limestone, ½ nat. size.

Fig. 168.

Helix occlusa, Edwards, nat. size. Bembridge Limestone, Isle of Wight.

Fig. 169.



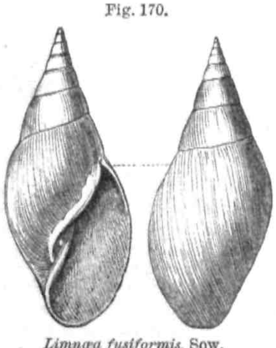
Paludina orbicularis, ½. Bembridge.

common, especially at Sconce, near Yarmouth, as described by Mr. F. Edwards. The *Bulimus ellipticus* (fig. 167) and *Helix occlusa* (fig. 168) are among its best-known land-shells. *Palu-*

Fig. 171.

Planorbis discus, Edwards. Bembridge, ½ diam.

Fig. 170.



Limnæa fusiformis, Sow. nat. size.

Fig. 172.

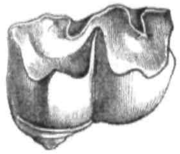
Chara tuberculata, seed-vessel, mag. Bembridge Limestone, I. of Wight.

dina orbicularis (fig. 169) is also of frequent occurrence. One of the bands is filled with a little globular *Paludina*. Among the freshwater pulmonifera, *Limnæa fusiformis*, Sow. (fig. 170), and *Planorbis discus* (fig. 171) are the most generally distributed: the latter represents or takes the place of the *Planorbis euomphalus* (see fig. 174) of the more ancient Headon series. *Chara*

tuberculata (fig. 172) is the characteristic Bembridge 'gyrogonite' or seed-vessel.

From this formation on the shores of Whitecliff Bay, Dr. Mantell obtained a fine specimen of a fan palm, *Flabellaria Lamanonis*, Brong., a plant first obtained from beds of corresponding age in the suburbs of Paris. The well-known building-stone of Binstead, near Ryde, a limestone with numerous hollows caused by *Cyrenæ* which have disappeared and left the moulds of their shells, belongs to this subdivision of the Bembridge series. In the same Binstead stone Mr. Pratt and the Rev. Darwin Fox first discovered the remains of mammalia characteristic of the gypseous series of Paris, such as *Palæotherium magnum*, *P. medium*, *P. minus*, *P. minimum*, *P. curtum*, *P. crassum*; also *Anoplotherium commune* (fig. 173), *A. secundarium*, *Dichobune cervinum*, and *Chæropotamus Cuvieri*. The Paleothere, above alluded to, resembled the living tapir in the form of the head, and in having a short proboscis, but its molar teeth were more like those of the rhinoceros. *Palæotherium magnum* was of the size of a horse, about four or five feet in height.

Fig. 173.



Lower molar tooth, nat. size. *Anoplotherium commune.* Binstead, Isle of Wight.

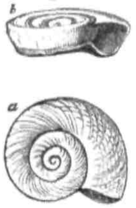
Osborne or St. Helen's series.—This group is of fresh and brackish-water origin, and very variable in mineral character and thickness. Near Ryde, it supplies a freestone much used for building, and called by Professor Forbes the Nettlestone grit. In one part ripple-marked flagstones occur, and rocks with fucoidal markings. The Osborne beds are distinguished by peculiar species of *Paludina*, *Melania*, and *Melanopsis*, as also of *Cypris* and the seeds of *Chara*.

Headon series.—These beds are seen both in Whitecliff Bay, Headon Hill, and Alum Bay, or at the east and west extremities of the Isle of Wight. The upper and lower portions are freshwater, and the middle are of mixed origin, sometimes brackish and then marine. Everywhere *Planorbis euomphalus* (fig. 174) characterises the freshwater deposits, just as the allied form, *P. discus* (fig. 171) does the Bembridge limestone. The brackish-water beds contain *Potamomya plana*, *Cerithium mutabile*, and *Potamides cinctus* (fig. 37, p. 31), and the marine beds *Venus* (or *Cytherea*) *incrassata*, a species common to the Limbourg beds and Grès de Fontainebleau, of the Oligocene series. The prevalence of marine species is most conspicuous in some of the central parts of the formation.

Among the shells which are widely distributed through the

Headon series are *Neritina concava* (fig. 176), *Limnæa caudata* (fig. 177), and *Cerithium concavum* (fig. 178). *Helix labyrinthica*, Say. (fig. 175), a land-shell now inhabiting the United States, was discovered in this series by Mr. Searles Wood in Hordwell

Fig. 174.



Planorbis euomphalus, Sow. Headon Hill, ½ diam.

Fig. 175.

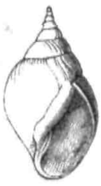
Helix labyrinthica, Say., Headon Hill, Isle of Wight; and Hordwell Cliff, Hants—also recent.

Cliff. It is also met with in Headon Hill, in the same beds. At Sconce, in the Isle of Wight, it occurs in the Bembridge series. The lower and middle portion of the Headon series is also met with in Hordwell Cliff (or Hordle, as it is often spelt),

Fig. 176.

Neritina concava, Sow., nat. size. Headon series.

Fig. 177.



Limnæa caudata, Edw., ½. Headon series.

Fig. 178.

Cerithium concavum, Sow., ⅔. Headon series.

near Lymington, Hants. The chief shells which abound in this cliff are *Paludina lenta* and various species of *Limnæa*, *Planorbis*, *Melania*, *Cyclas*, *Unio*, *Potamomya*, *Dreissena*, &c.

Among the chelonians we find a species of *Emys*, and no less than six species of *Trionyx*; among the saurians an alligator and a crocodile; among the ophidians two species of land-snakes (*Paleryx*, Owen); and among the fish, Sir P. Egerton and Mr. Wood have found the jaws, teeth, and hard, shining scales of the genus *Lepidosteus*, or Bony pike of the American rivers. The same genus of freshwater ganoids has also been met with in the Hempstead beds in the Isle of Wight. The bones of several birds have been obtained from Hordwell, and the remains of quadrupeds of the genera *Palæotherium* (*P. minus*),

Anoplotherium, *Dichodon*, *Dichobune*, *Hyracotherium*, *Microchærus*, *Lophiodon*, *Hyopotamus*, and *Hyænodon*. The latter is allied to the marsupial *Thylacinus*, and offers, I believe, the oldest known example of a true carnivorous animal in the series of British fossils; although I attach very little theoretical importance to the fact, because herbivorous species are those most easily met with in a fossil state in all save cavern deposits. *Limnofelis* is the earliest Cat and is from the Middle Eocene of N. America. In another point of view, however, this fauna deserves notice. Its geological position is considerably lower than that of the Bembridge or Montmartre beds, from which it differs almost as much in species as it does from the still more ancient fauna of the Eocene beds. It therefore teaches us what a grand succession of distinct assemblages of mammalia flourished on the earth during the Tertiary period.

Many of the marine shells of the brackish water beds of the above series, both in the Isle of Wight and Hordwell Cliff, are common to the underlying Barton Clay; and, on the other hand, there are some freshwater shells, such as *Cyrena obovata*, which are common to the Bembridge beds, notwithstanding the intervention of the St. Helen's series.

At Brockenhurst, near Lyndhurst, in the New Forest, marine strata have recently been found, containing 59 species of shells, many of which have been described by Mr. Edwards. These beds rest on the Lower Headon, and are considered as the equivalent of the middle part of the Headon series, many of the shells being common to the brackish-water or Middle Headon beds of Colwell and Whitecliff Bays, such as *Cancellaria muricata*, Sow., *Fusus labiatus*, Sow., &c. In these beds at Brockenhurst, corals, described by Dr. P. Martin Duncan, have been found in abundance and in considerable perfection. (See fig. 179, *Solenastræa cellulosa*.)

Fig. 179.

Solenastræa cellulosa, Dunc., nat. size. Brockenhurst.

Among the fossils found in the Middle Headon are *Cytherea incrassata* and *Cerithium plicatum* (fig. 161, p. 208). These shells, especially the latter, are very characteristic of the Oligocene.

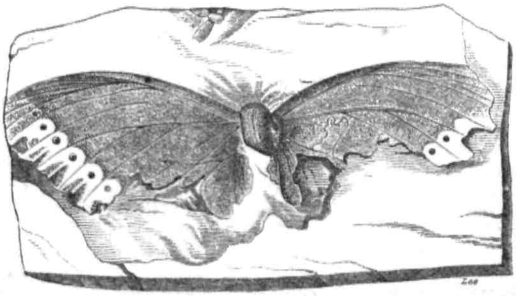
Baron von Koenen has pointed out that no less than 46 out of the 59 Brockenhurst shells, or a proportion of 78 per cent., agree with species occurring in the Tongrian formation in Belgium.

The marine band of the Headon series has yielded 235 species of fossils, and 14 species of corals. A very considerable proportion of these species is common to the Oligocene beds of the Continent, and 22 species ascend from the Eocene beds below.

The equivalency of the Headon series with the Tongrian, as now limited in Belgium (p. 201) is exact, and it appears that the Osborne, Bembridge, and Hempstead strata represent the Rupelian Oligocene of the Continent. The Hempstead beds may be the equivalents of the Fontainebleau sands.

Oligocene beds of Croatia.—The Brown Coal of Radaboj, near Agram, in Croatia, not far from the borders of Styria, is covered, says Von Buch, by beds containing the marine shells of the Vienna basin (p. 193). The strata correspond in age to the Middle Oligocene of Belgium. They have yielded more than 200 species of fossil plants, described by the late Professor Unger. These plants are well preserved in a hard marlstone, and contain several palms; among them the Sabal (fig. 154, p. 204), and another genus allied to the date-palm, *Phœnicites spectabilis*. The only abundant plant among the Radaboj fossils which is characteristic of the Miocene period is the *Populus mutabilis*, whereas no less than fifty of the Radaboj species are

Fig. 180.



Vanessa Pluto; nat. size. Oligocene, Radaboj, Croatia.

common to the more ancient flora of the Lower Molasse or Oligocene of Switzerland.

The insect fauna is very rich, and, like the plants, indicates a more tropical climate than do the fossils of Œningen already mentioned. There are ten species of *Termites*, or White ants, some of gigantic size, and large dragon-flies with speckled wings, like those of the southern States in North America; there are also grasshoppers of considerable size, and even the

Lepidoptera are not unrepresented. In one instance, the pattern of a butterfly's wing has escaped obliteration in the marlstone of Radaboj; and when we reflect on the remoteness of the time from which it has been faithfully transmitted to us, this fact may inspire the reader with some confidence as to the reliable nature of the characters which other insects of a more durable texture, such as the beetles, may afford for specific determination. The Vanessa (fig. 180) retains, says Heer, some of its colours, and corresponds with *V. Hadena* of India.

In the Vienna basin are Oligocene strata with *Cerithium plicatum* in the marine layers and *Melania* in the freshwater deposits, with *Mastodon tapiroides*, *Rhinoceros sansaniensis*, *Amphicyon*, and *Anchitherium*.

The Miocene of India, in Sind, rests upon an important Oligocene series called the Nari series, which contains a characteristic fauna of reef-building corals, and very flat Echinolampads, with a few late Nummulites. No Nummulites are found in the Miocene strata above.

CHAPTER XVI.

EOCENE FORMATIONS.

Eocene areas of North of Europe—Table of English strata—Upper Eocene of England—Barton sands and clays—Middle Eocene of England—Shells, nummulites, fish, and reptiles of the Bracklesham beds and Bagshot sands—Plants of Alum Bay and Bournemouth—Bovey Tracey, Mull, and Antrim—Arctic Eocene flora—Lower Eocene of England—London clay fossils—Woolwich and Reading beds formerly called 'Plastic clay'—Thanet sands—Upper Eocene strata of France—Marine gypseous series of Montmartre and Sables moyens—Grès de Beauchamp—Calcaire grossier—Miliolite limestone—Glauconie grossière—Lower Eocene of France—Soissonais sands—Argile plastique—Sables de Bracheux—Rilly beds.

Eocene areas of the North of Europe.—The strata next in order in the descending series, are those which I term Eocene. In the accompanying map, the position of several Eocene areas in the North of Europe is pointed out. When this map was constructed I classed, as the newer part of the Eocene, those Tertiary strata which have been described in the last chapter as Oligocene. None of these occur in the London Basin, and they occupy in that of Hampshire, as may be conceived, too insignificant a superficial area to be noticed in a map on this scale. They fill a larger space in the Paris Basin between

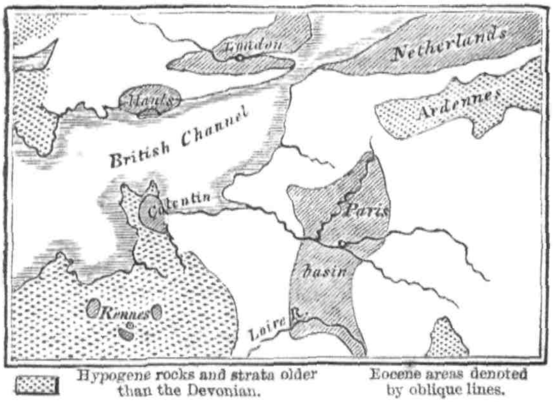
the Seine and the Loire, and constitute also a part of the northern limits of the area of the Netherlands which are shaded in the map.

The Eocene strata, with the exception of certain plant beds, are confined in Great Britain to the south-east, and they occupy two synclinal basins which have been separated by denudation.

It is in the northern part of the Isle of Wight that we have the uppermost beds of the true Eocene best exhibited—namely,

Fig. 181.

Map of the principal Eocene areas of North-Western Europe.



N.B. The space left blank is occupied by fossiliferous formations from the Devonian to the chalk inclusive.

those which correspond in their fossils with the marine gypsum of the Paris Basin (see Table, p. 103). This gypsum has been selected by almost all continental geologists as affording the best line of demarcation between the Oligocene and Eocene formations.

The correlation of the French, English, and Belgian subdivisions is often a matter of great doubt and difficulty, notwithstanding their geographical proximity. This arises from various circumstances, partly from the former prevalence of marine conditions in one basin simultaneously with fluviatile or lacustrine in the other, and sometimes from the existence of land in one area causing a break or absence of all records during a period when deposits may have been in progress in the other basin. As bearing on this subject, it may be stated that we have unquestionable evidence of oscillations of level shown by the superposition of salt or brackish-water strata to fluviatile beds; and

those of deep-sea origin to strata formed in shallow water. Even if the upward and downward movements were uniform in amount and direction, which is very improbable, their effect in producing the conversion of sea into land, or land into sea, would be different according to the previous shape and varying elevation of the land and bottom of the sea. Lastly, denudation, marine and subaërial, has frequently caused the absence of deposits in one basin of corresponding age to those in the other, and this destructive agency has been more than ordinarily effective on account of the loose and unconsolidated nature of the sands and clays.

The following is the arrangement of the strata in the London and Hampshire areas or Basins :—

	Hampshire.	London.
Upper Eocene.	Barton clay.	Upper Bagshot sands.
Middle Eocene	Bracklesham and leaf bed series of Alum Bay and Bournemouth.	Middle Bagshot sands.
Lower Eocene.	Bognor beds.	Lower Bagshot sands. London clay. Oldhaven beds.
	Woolwich and Reading series.	Woolwich and Reading series.
	Thanet sands wanting.	Thanet sands.

UPPER EOCENE.

Barton Clay.—This clay does not occur in the London Basin, where probably the *Upper Bagshot sands* are its geological equivalents. It consists of grey, greenish, and brown clays, with bands of sand. It is seen vertical in Alum Bay, Isle of Wight, and nearly horizontal in the cliffs of the mainland near Lymington. The thickness is 300 feet at Barton Cliff, and it is rich in marine fossils.

Fig. 182.

Chama squamosa, Eichw., ½. Barton.

Usually, the fossils are beautifully preserved, and *Chama squamosa*, found by Dr. T. Wright in the sandy beds, is very characteristic.

Certain foraminifera called Nummulites begin, when we study the Tertiary formations in a descending order, to make their first appearance in these beds. *Nummulites planulatus* and a small species called *Nummulites variolarius* (fig. 191), are found both on the Hampshire coast and in beds of the same age in Whitecliff Bay, in the Isle of Wight. Several marine shells, among which is *Corbula pisum* (fig. 159, p. 208), are common to the Barton beds and the higher Hempstead series, and a still greater number are common to the Headon series.

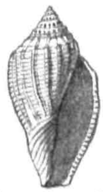
MIDDLE EOCENE, ENGLAND.

Bracklesham Beds and Middle Bagshot Sands.—Beneath the Barton Clay we find in the north of the Isle of Wight, both

Fig. 183.

Mitra scabra, Sow., nat. size.

Fig. 184.



Voluta ambigua, Sol., ½.

Fig. 185.

Typhis pungens, Brand., nat. size.

Fig. 186.

Voluta athleta, Sol., ½. Barton and Bracklesham.

Fig. 187.

Terebellum fusiforme, Lam., nat. size. Barton and Bracklesham.

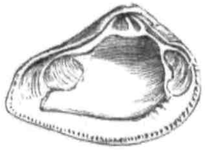
Fig. 188.

Terebellum sopita, Brand.

Fig. 189.

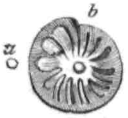
Cardita sulcata, Brand., ⅔. Barton.

Fig. 190.



Crassatella sulcata, Sow., ½. Bracklesham and Barton.

Fig. 191.

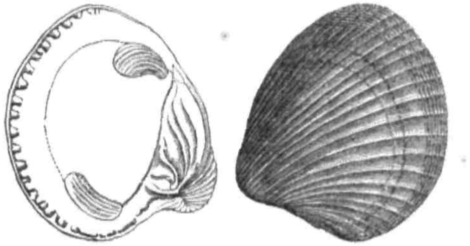


Nummulites variolarius, Lam. Var. of *N. radiata*, Sow., Mid. Eocene, Bracklesham Bay. *a.* Nat. size. *b.* Magnified.

in Alum and Whitecliff Bays, a great series of various-coloured sands and clays for the most part unfossiliferous, and probably of estuarine origin. As some of these beds contain *Cardita planicosta* (fig. 192) they have been identified with the marine beds much richer in fossils seen in the coast section in Bracklesham Bay, near Chichester in Sussex, where the strata consist

chiefly of green clayey sands with some lignite. Among the Bracklesham fossils, besides the Cardita, occurs the huge *Cerithium giganteum*, so conspicuous in the Calcaire grossier of

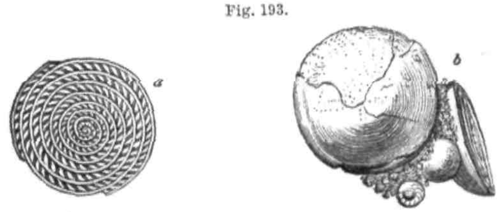
Fig. 192.



Cardita (*Venericardia*) *planicosta*, Lam., ½.

Paris, where it is sometimes two feet in length. *Nummulites lævigatus* (see fig. 193), so characteristic of the lower beds of the Calcaire grossier in France, where it sometimes forms stony layers, as near Compeigne, is also very common in these beds,

Fig. 193.



Nummulites (*Nummularia*) *lævigatus*. Bracklesham. Dixon's Fossils of Sussex, Pl. 8, nat. size.

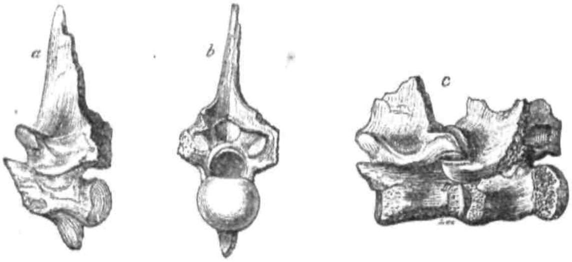
a. Section of the nummulite.
b. Group, with an individual showing the exterior of the shell.

together with *N. scaber* and *N. variolarius*. Out of 193 species of testacea procured from the Bagshot and Bracklesham beds in England, 126 occur in the Calcaire grossier in France. It was clearly, therefore, coeval with that part of the Parisian series, more nearly than with any other.

According to tables compiled from the best authorities by Mr. Etheridge, the number of mollusca now known from the Bracklesham beds in Great Britain is 393, of which no less than 240 are peculiar to this subdivision of the British Eocene series, while 70 are common to the older London Clay, and 140 to the Newer Barton Clay. The Volutes and cowries of this formation, as well as the Bryozoa and corals, favour the idea of a warm

climate having prevailed, which is borne out by the discovery of the remains of a serpent, *Palæophis typhœus* (see fig. 194),

Fig. 194.



Palæophis typhœus, Owen, ½; an Eocene sea-serpent. Bracklesham.

a, *b*. Vertebra, with long neural spine preserved.
c. Two vertebræ articulated together.

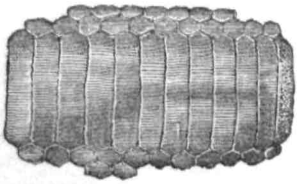
exceeding, according to Professor Owen, twenty feet in length, and allied in its osteology to the Boa, *Python*, *Coluber*, and

Fig. 195.

Defensive spine of Ostraceon, ⅓. Bracklesham.

Hydrophis. The compressed form and diminutive size of certain caudal vertebræ indicate so much analogy with *Hydrophidæ* as to induce Professor Owen to pronounce this extinct ophidian to have been marine.[1] Amongst the companions of the sea-snake of Bracklesham was an extinct crocodile (*Gavialis Dixoni*, Owen), and numerous fish, such as now frequent the seas of warm latitudes, as the Ostraceon of the family Balistidæ, of which a dorsal spine is figured (see fig. 195), and gigantic Rays of the genus *Myliobates* (see fig. 196).

Fig. 196.



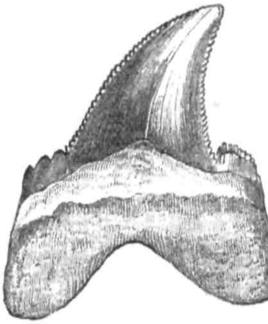
Palatal or dental plates of *Myliobates Edwardsi*, ½. Bracklesham Bay. Dixon's Fossils of Sussex, Pl. 8.

The teeth of sharks also, of the genera *Carcharodon*, *Otodus*, *Lamna*, *Galeocerdo*, and others, are abundant. (See figs. 197, 198, 199, 200.)

[1] Paleont. Soc. Monograph. Rept. pt. ii. p. 61.

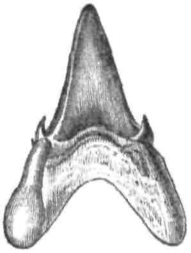
Alum Bay and Bournemouth Beds (*Middle Bagshot*).—The sands and clays which intervene between the equivalents of the Bracklesham Beds and the London Clay or Lower Eocene, are well seen in the vertical beds of Alum Bay in the Isle of Wight and eastwards of Bournemouth on the south coast

Fig. 197.



Carcharodon angustidens, Agass.

Fig. 198.

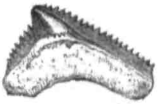


Otodus obliquus, Agass., nat. size.

Fig. 199.

Lamna elegans, Agass., nat. size.

Fig. 200.



Galeocerdo latidens, Agass., nat. size.

Teeth of Sharks from Bracklesham Beds.

Marine Shells of Bracklesham Beds.

Fig. 201.

Pleurotoma attenuata, Sow., ½.

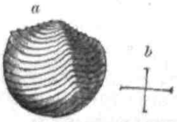
Fig. 202.

Voluta Selseiensis, Edwards, ½.

Fig. 203.

Turritella multisulcata, Lam., ½.

Fig. 204.



Lucina serrata, Sow. *a*. Magnified. *b*. Nat. size.

Fig. 205.

Conus deperditus, Brug., ½.

of Hampshire. There are some leaf-beds which underlie the marine strata of Bracklesham clays of this locality.

None of the beds are of great horizontal extent, and there is much cross-stratification or false-bedding in the sands, and in some places black carbonaceous seams and lignite. In the midst of a leaf-bed at the base of the Bournemouth strata in

Studland Bay, Dorsetshire, shells of the genus Unio attest the freshwater origin of the white clay.

No less than 40 species of plants are mentioned by MM. De la Harpe and Gaudin from this formation in Hampshire, among which the Proteaceæ (*Dryandra*, &c.) and the fig tribe are abundant, as well as the cinnamon and several other laurineæ, with some papillionaceous plants.

It appears from the researches of Mr. Starkie Gardner that the leaves, fruits, and seeds were deposited close to where they once grew. The fruit *Nipadites*, closely allied to that of the existing Nipa Palm, was found with the rhind and pulp more or less preserved. Tufts of leaves of *Proteaceæ*, branches of *Coniferæ*, seeds of *Hightea minima*, Bow., and *Anona* were observed. A small patch at the base of the cliffs was crowded with seeds of *Hightea cucummites* and *Petrophiloides*. Pinnae of an *Osmunda* were present. There is a fine *Irartea* palm-leaf in the British Museum from this locality.

Heer has mentioned several species which are common to this flora and that of Monte Bolca, near Verona, so celebrated for its fossil fish, and where the strata contain nummulites and other Middle Eocene fossils. He has particularly alluded to *Aralia primigenia* (of which genus a fruit has since been found by Mr. Mitchell at Bournemouth), *Daphnogene veronensis*, and *Ficus granadilla*, as among the species common to and characteristic of the Isle of Wight and Italian Eocene beds. The American types of Eocene plants are noticed.

Lignites and Clays of Bovey Tracey, Devonshire.—Surrounded by the granite and other rocks of the Dartmoor hill in Devonshire, is a formation of kaolin clay, sand, and lignite, long known to geologists as the Bovey Coal formation, respecting the age of which, until late years, opinions were very unsettled. This deposit is situated at Bovey Tracey, a village distant eleven miles from Exeter in a south-west, and about as far from Torquay in a north-west, direction. The strata extend over a plain nine miles long, and they consist of the materials of decomposed and worn-down granite mixed with vegetable matter, and have evidently filled up an ancient hollow or lake-like expansion of the valleys of the Bovey and Teign.

The lignite is of bad quality for economical purposes, having a great admixture of iron pyrites, and emitting a sulphurous odour; it has, however, been successfully applied to the baking of pottery, for which some of the fine clays are well adapted. Mr. Pengelly has confirmed Sir H. De la Beche's opinion that much of the upper portion of this old lacustrine formation has been removed by denudation.[2]

[2] Phil. Trans. 1863. W. Pengelly, F.R.S. and Dr. Oswald Heer.

At the surface is a dense covering of white clay and gravel with angular stones probably of the Pleistocene period, for in the clay are three species of willow and the dwarf birch *Betula nana*, indicating a climate colder than that of Devonshire at the present day.

Below this are Middle Eocene strata about 300 feet in thickness, in the upper part of which are twenty-six beds of lignite, clay, and sand, and at their base a ferruginous quartzose sand, varying in thickness from two to twenty-seven feet. Below this sand are forty-five beds of alternating lignite and clay. No shells or bones of mammalia, and no insect, with the exception of one fragment of a beetle (*Bupestris*)—in a word, no organic remains, except plants, have as yet been found. These plants occur in fourteen of the beds; namely, in two of the clays, and the rest in the lignites. Amongst the species are a number of ferns—*Lastræa stiriaca*, *Pecopteris lignitum*; conifers—*Sequoia Couttsiæ*, the matted *débris* of which form a lignite bed. There are also the genera *Cinnamomum*, *Eucalyptus*, *Quercus*, *Salix*, *Laurus*, *Anona*, *Palmacites*, leaves of evergreen oaks, spindle trees, figs, water-lily, and the grape-stones or seeds of two species of vine.

The croziers of some of the young ferns are very perfect, and were at first mistaken, by collectors, for shells of the genus *Planorbis*. On the whole, the vegetation of Bovey implies the existence of a sub-tropical climate in Devonshire in the Middle Eocene period.

Scotland.—Isle of Mull.—In the sea-cliffs, forming the headland of Ardtun, on the west coast of Mull, in the Hebrides, several bands of tertiary strata containing leaves of dicotyledonous plants were discovered in 1851 by the Duke of Argyll.[3] From his description it appears that there are three leaf-beds, varying in thickness from 1½ to 2½ feet, which are interstratified with volcanic tuff and trap, the whole mass being about 130 feet in thickness. A sheet of basalt of later age, 40 feet thick, covers the whole; and another columnar bed of the same rock, 10 feet thick, is exposed at the bottom of the cliff. One of the leaf-beds consists of a compressed mass of leaves unaccompanied by any stems, as if they had been blown into a marsh where a species of *Equisetum* grew, of which the remains are plentifully embedded in clay.

It is supposed by the Duke of Argyll that this formation was accumulated in a shallow lake or marsh in the neighbourhood of a volcano, which emitted showers of ashes and streams of lava. The tufaceous envelope of the fossils may have fallen into the lake from the air as volcanic dust, or have been washed down

[3] Quart. Jour. Geol. Soc. 1851, p. 19.

into it as mud from the adjoining land. Even without the aid of Tertiary fossil plants, we might have decided that the deposit was newer than the chalk, for chalk flints containing cretaceous fossils were detected by the Duke in the principal mass of volcanic ashes or tuff.[4]

The late Edward Forbes observed that some of the plants of this formation resembled those of Croatia, described by Dr. Unger; and his opinion has been confirmed by Professor Heer, who found that the conifer most prevalent was the *Sequoia Langsdorfii* (fig. 156, p. 205), also *Corylus grosse-dentata*, an Oligocene species of Switzerland and of Menat, in Auvergne. There is likewise a plane tree, the leaves of which seem to agree with those of *Platanus aceroides* (fig. 146, p. 188), and a fern, *Filicites hebridica*, Forbes, which is as yet peculiar as a European fossil to Mull, but which is considered by Dr. Newberry to be identical with a living American species, *Onoclea sensibilis*. It is most probable, however, that these beds belong to the horizon of Bovey Tracey and Bournemouth, being, according to Mr. Starkie Gardner, of Eocene age.

Ireland.—These interesting discoveries in Mull lead to the suspicion that the basalt of Antrim and of the Giant's Causeway, in Ireland, may be of the same Eocene age. The volcanic rocks that overlie the chalk, and some of the strata associated with, and interstratified between masses of basalt, contain leaves of dicotyledonous plants, somewhat imperfect, but resembling the beech, oak, and plane, and also some coniferæ of the genera *Pinus* and *Sequoia*. These old land surfaces are exceedingly interesting.

Arctic Eocene Flora.—A rich terrestrial flora flourished in the Arctic regions in the Eocene period, many species of which are common to the Eocene strata of North-West Europe. Professor Heer has examined the various collections of fossil plants that have been obtained in N. Greenland (lat. 70°),[5] Iceland, Spitzbergen, and other parts of the Arctic regions, and has determined that they indicate a temperate climate.[6] Including the collections recently brought from Greenland by Mr. Whymper, this Arctic flora now comprises 353 species, and that of Greenland 169 species, of which 69, or nearly two-fifths, were supposed to be identical with plants found in the Miocene beds of Central Europe. Considerably more than half the

[4] Quart. Journ. G. S. 1851, p. 90.

[5] During the last English Polar Expedition to N. Greenland, 1875, twenty-five species of plants of Miocene âge were found by Captain Feilden in Grinnell-land, 81° 45′ N. lat., and described by Prof. Heer, Q. J. G. Soc. vol. xxxiv. p. 66.

[6] Heer, Flora Fossilis Arctica, and Fossil-Flora von Alaska, 1869.

number are trees, which is the more remarkable since at the present day trees do not exist in any part of Greenland even 10° farther south.

More than 50 species of Coniferæ have been found, including several Sequoias (allied to the gigantic Wellingtonia of California), with species of *Thujopsis* and *Salisburia* now peculiar to Japan. There are also beeches, oaks, planes, poplars, maples, walnuts, limes, and even a *Magnolia*, two cones of which have recently been obtained, proving that this splendid tree not only lived but ripened its fruit within the Arctic circle. Many of the limes, planes, and oaks were large-leaved species, and both flowers and fruit, besides immense quantities of leaves, are in many cases preserved. Among the shrubs were many evergreens, as *Andromeda*, and two extinct genera, *Daphnogene* and *M'Clintockia*, with fine leathery leaves, together with hazel, blackthorn, holly, logwood, and hawthorn. *Potamogeton*, *Sparganium*, and *Menyanthes* grew in the swamps, while ivy and vines twined around the forest trees, and broad-leaved ferns grew beneath their shade. Even in Spitzbergen, as far north as lat. 78° 56′, no less than 179 species of fossil plants have been obtained, including *Taxodium* of two species, hazel, poplar, alder, beech, plane-tree, and lime.[7] Such a vigorous growth of trees within 12° of the Pole, where now a dwarf willow and a few herbaceous plants form the only vegetation, and where the ground is covered with almost perpetual snow and ice, is truly remarkable.

Professor Heer believes that the mean temperature of North Greenland must have been at least 30° higher than at present, while an addition of 10° to the mean temperature of Central Europe would probably be as much as was required. The chief locality where this wonderful flora is preserved is at Atanekerdluk in North Greenland (lat. 70°), on a hill at an elevation of about 1,200 feet above the sea. There is here a considerable succession of sedimentary strata pierced by volcanic rocks. Fossil plants occur in all the beds; and the erect trunks as thick as a man's body, which are sometimes found, together with the abundance of specimens of flowers and fruit in good preservation, sufficiently prove that the plants grew where they are now found. At Disco Island and other localities on the same part of the coast, good tertiary coal is abundant, interstratified with beds of sandstone, in some of which fossil plants have also been found, similar to those at Atanekerdluk.

A rather different flora was found under glacial marine drift

[7] Heer, Miocene Flora and Fauna of Spitzbergen. Stockholm, 1875.

1,000 feet above the present sea level of Robeson Channel, N. lat. 81° 45′, long. W. 64° 45′. Twenty-six species were noticed, and eighteen had been found in the Eocene deposits of Spitzbergen and Greenland. The Coniferæ with *Taxodium distichum*, are abundant, this last being found in a state of bloom. *Pinus abies* occurred whose extreme limit is now N. lat. 69° 30′, but it spreads over 25 degrees of latitude. It was only Arctic in the Eocene. Large reeds, poplar, birch, hazel, elm, and water-lily occurred; but the large-leaved plants like *Magnolia* were not discovered.

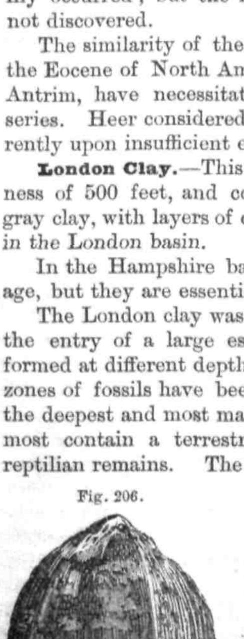
The similarity of these Tertiary Arctic floras with those of the Eocene of North America and of Bournemouth, Mull, and Antrim, have necessitated their being placed in the Eocene series. Heer considered them to be of Miocene age, and apparently upon insufficient evidence.

London Clay.—This formation sometimes attains a thickness of 500 feet, and consists of tenacious brown and bluish-gray clay, with layers of concretions called septaria, and is found in the London basin.

In the Hampshire basin the Bognor beds are of the same age, but they are essentially marine.

The London clay was partly deposited on a sea-floor close to the entry of a large estuary and river, and the strata were formed at different depths, and some in shallow water. Several zones of fossils have been discovered by Professor Prestwich; the deepest and most marine being to the east, and the uppermost contain a terrestrial vegetation, mammalian, fish, and reptilian remains. The following genera of plants and others have been noticed by Bowerbank, Ettingshausen, and Gardner: *Pinus*, *Collitris*, *Salisburia*, *Musa*, *Sabal*, *Nipadites*, *Livistonia*, *Quercus*, *Liquidambar*, *Nysa*, *Magnolia*, *Juglans*, *Eucalyptus*, *Amygdalis*, *Bankinia*.

Fig. 206.



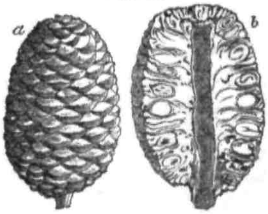
Nipadites ellipticus, Bow., ⅔. Fossil fruit of palm, from Sheppey.

Mr. Bowerbank, in a valuable publication on these fossil fruits and seeds, has described fruits of palms of the recent type *Nipa*, now only found in the Molucca and Philippine Islands, and in Bengal. (See fig. 206.) In the delta of the Ganges, Sir J. Hooker observed the large nuts of *Nipa fruticans* floating in such numbers in the various arms of that great river as to obstruct the paddle-wheels of steam-boats. These plants are allied to the cocoa-nut tribe on the one side, and on

the other to the *Pandanus*, or screw-pine. There are also met with three species of *Anona*, or custard apple; and cucurbitaceous fruits (of the gourd and melon family), and fruits of various species of *Acacia*.

Besides fir-cones or fruit of true Coniferæ there are cones of Proteaceæ in abundance, and the celebrated botanist, the late Robert Brown, pointed out the affinity of these to the New Holland types *Petrophila* and *Isopogon*. Of the first there are about 50 and the second 30 described species now living in Australia.

Fig. 207.



Eocene Proteaceous Fruit. *Petrophiloides Richardsoni*, London clay. Sheppey. Natural size. *a.* Cone. *b.* Section of cone showing the position of the seeds.

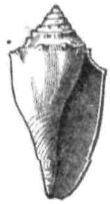
Baron Ettingshausen and Mr. Carruthers, having examined the original specimens now in the British Museum, tell me that all these cones from Sheppey (see fig. 207) may be reduced to two species, which have an undoubted affinity to the two existing Australian genera above mentioned.

The contiguity of land may be inferred not only from these vegetable productions, but also from the teeth and bones of crocodiles and turtles. Of turtles there were numerous species referred to extinct genera. These are, for the most part, not equal in size to the largest living tropical turtles. A sea-snake, thirteen feet in length, *Palæophis toliapicus*, has been described by Sir R. Owen from Sheppey, and the species differs from that of Bracklesham. A crocodile, *Crocodilus toliapicus*, has been described by the same great palæontologist, and a form nearly allied to the Gangetic Gavial also. The relics of several genera of Birds have been found of the genera *Lithornis*, *Argillornis*, and *Halcyornis*. The first was a Vulturine, the second an Albatross, and the third a King Fisher. Moreover, *Odontopteryx* represented the birds whose bony jaw margins are produced as denticulations. The Mammalian remains are very rare, *Hyracotherium*, an odd-hoofed herbivore, and *Lophiodon*, allied to the modern Tapir, have been found at the base of the formation, with a part of a jaw of a *Didelphys* (Opossum), discovered by Mr. Charlesworth, and the tooth of a Bat (*Vespertilio*). The species *Coryphodon eocænus*, Owen, most probably came from the underlying Woolwich beds. Nevertheless, this scanty fauna of a Herbivore, a Marsupial and an Insectivorous Bat is not without its interest. All seem to have inhabited the banks of the great river which floated down the Sheppey fruits. This

fauna was long antecedent to the present ... Europe and Asia, for the Alps and Himalay... washed by the sea, and ages had to elapse befor... heaval.

SHELLS OF THE LONDON CLAY.

Fig. 208.

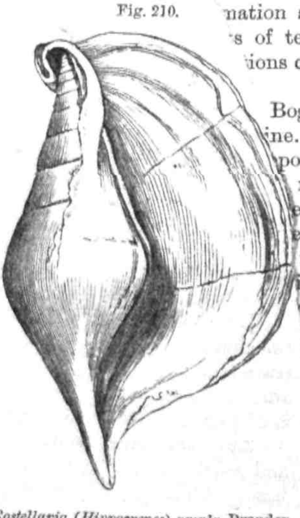


Voluta nodosa, Sow., ½. Highgate.

Fig. 209.

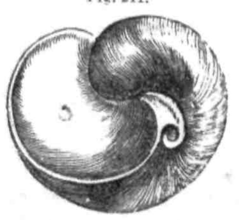
Phorus extensus, Sow., ½. Highgate.

Fig. 210.



Rostellaria (Hippocrenes) ampla, Brander, ⅓ of nat. size; also found in the Barton clay.

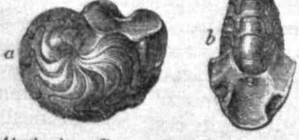
Fig. 211.



Nautilus centralis, Sow., ⅓. Highgate.

The marine shells of the London clay confirm the inference derivable from the plants and reptiles in favour of a high temperature. Thus many species of *Conus* and *Voluta* occur, a large

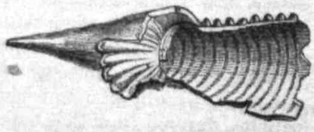
Fig. 212.



a b

Aturia ziczac, Bronn., Syn. *Nautilus ziczac*, Sow. London clay. Sheppey. ⅓.

Fig. 213.



Belosepia sepioidea, De Blainv., nat. size, London clay. Sheppey.

Cypræa, *C. oviformis*, a very large *Rostellaria* (fig. 210), a species of *Cancellaria* ...

1,000 feet above the present sea level of Ro... spect of nature in lat. 81° 45′, long. W. 64° 45′. Twenty-six species ... were low hills eighteen had been found in the Eocene deposits ... their final up and Greenland. The Coniferæ with *Taxodium d*... abundant, this last being found in a state of bloom ... *abies* occurred whose extreme limit is now N. lat. 69° ... er 25 degrees of latitude. It was only Ar... Large reeds, poplar, birch, hazel, elm, and w... ...ut the large-leaved plants like *Magnolia* ... of these Tertiary Arctic floras with those ... America and of Bournemouth, Mull, at ... ...ated their being placed in the Eocen... them to be of Miocene age, and appa... ...lence.

...nation sometimes attains a thick... ...s of tenacious brown and bluish... ...ions called septaria, and is found ...

... Bognor beds are of the same ...ne. ...posited on a sea-floor close to ... river, and the strata were ... in shallow water. Several ...ed by Professor Prestwich; ... to the east, and the upper... ...ion, mammalian, fish, and ...enera of plants and others ... noticed by Bowerbank, ...en, and Gardner: *Pinus*, ...*isburia*, *Musa*, *Sabal*, *Ni*... ...*stonia*, *Quercus*, *Liquidam*... *Magnolia*, *Juglans*, *Euca*... ...*gdalis*, *Bankinia*.

...erbank, in a valuable pub... ...ese fossil fruits and seeds, ...d fruits of palms of the *Nipa*, now only found in ... and Philippine Islands, ...l. (See fig. 206.) In the ... Ganges, Sir J. Hooker ... large nuts of *Nipa fru*... ...arious arms of that great ... of steam-boats. These ... on the one side, and on

which is the *Belosepia* (fig. 213). Among many characteristic bivalve shells are *Leda amygdaloides* (fig. 214) and *Cryptodon angulatum* (fig. 215), and among the Radiata a star-fish, *Astro pecten* (fig. 216).

Nearly 100 species of fish, amongst which there are a sword-fish (*Tetrapterus priscus*, Agassiz), about eight feet long, and a

Fig. 214.

Leda amygdaloides, Sow., ⅔. Highgate.

Fig. 215.

Cryptodon (*Axinus*) *angulatum*, Sow., nat. size. London clay, Hornsey.

Fig. 216.

Astropecten crispatus, E. Forbes, ½. Sheppey.

saw-fish (*Pristis bisulcatus*, Ag.), about ten feet in length, both now foreign to the British seas.

The Crustacea were abundant, and most of them belonged to the short-tailed tribe ; one species may have belonged to the true crabs (?). The other genera found are *Xanthopsis*, *Xantholithes*, and *Grapsus*. One of the Anomura, with a moderately long abdomen, was Dromilites, allied to the Sponge-crab.

The Oldhaven Beds form the base of the London clay, and consist almost entirely of rolled flint pebbles in a sandy base. Although only twenty to thirty feet thick, 150 species of fossils have been yielded, consisting of marine and estuarine shells and plant remains. The flora, so far as it goes, is interesting, and contains *Ficus*, *Cinnamomum*, and Coniferæ, and appears to be without the American and Australian types which were so dominant in later times.

Woolwich and Reading series.—This formation was formerly called the Plastic clay, as it agrees with a similar clay used in pottery, which occupies the same position in the French series, and it has been used for the like purposes in England.

This formation, when studied in the basins of London, Hampshire, and Paris, presents very variable characters ; but typically the beds consist, over a large area, of mottled clays and sand, with lignite, and with some strata of well-rolled flint-pebbles, derived from the chalk, varying in size, but occasionally several inches in diameter. These strata may be seen in the Isle of Wight or at Bognor, in contact with the chalk ; or in the London basin, at Reading, Blackheath, and Woolwich, covering the Thanet sand. In the lowest beds, banks of oysters are observed, consisting of *Ostrea bellovacina*, common also in France,

(fig. 221), *Corbula longirostris*, *Scalaria Bowerbankii*, *Aporrhais Sowerbyi* (fig. 220).

North of France.—Upper Eocene.—The strata of this age in the Paris basin are continuous downwards with the Lower Oligocene. They are the marine gypseous series, yellow and greenish marls, with *Cerithium tricarinatum* and *Pholadomya ludensis*.

Beneath these are the 'Sables moyens,' with green sands overlying the nearly freshwater limestone of St. Ouen. They rest on the Grès de Beauchamp, placed upon a marine sandstone with corals, sharks' teeth, and *Nummulites variolarius*.

The Middle Eocene is composed of the Calcaire grossier, formed of limestones, siliceous limestones, and sandy glauconitic beds at the base, all highly fossiliferous.

The upper division of this group consists in great part, of beds of compact, fragile limestone, with some intercalated green marls. The shells in some parts are a mixture of *Cerithium*, *Cyclostoma*, and *Corbula*; in others *Limnæa*, *Cerithium*, *Paludina*, &c. In the latter, the bones of reptiles and mammalia, *Palæotherium* and *Lophiodon*, have been found. The middle division, or Calcaire grossier proper, consists of a coarse limestone, often passing into sand. It contains the greater number of the fossil shells which characterise the Paris Basin. No less than 400 distinct species have been procured from a single spot near Grignon, where they are embedded in a calcareous sand, chiefly formed of comminuted shells, in which, nevertheless, individuals in a perfect state of preservation, both of marine, terrestrial, and freshwater species, are mingled together. Some of the marine shells may have lived on the spot; but the *Cyclostomæ* and *Limnææ*, being land and freshwater shells, must have been brought thither by rivers and currents.

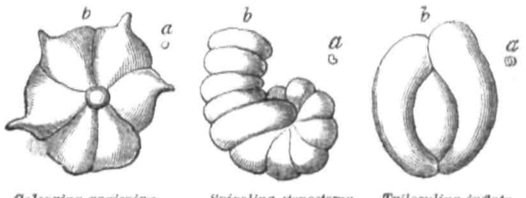
Nothing is more striking in this assemblage of fossil testacea than the great proportion of species referable to the genus *Cerithium* (see figs. p. 208). There occur no less than 137 species of this genus in the Paris Basin, and almost all of them in the Calcaire grossier. Most of the living *Cerithia* inhabit the sea near the mouths of rivers, where the waters are brackish; so that their abundance in the marine strata now under consideration is in harmony with the hypothesis that the Paris Basin formed a gulf into which several rivers flowed.

In some parts of the Calcaire grossier round Paris, certain beds occur of a stone used in building, and called by the French geologists 'Miliolite limestone.' It is almost entirely made up of millions of microscopic shells, of the size of minute grains of sand, which all belong to the class Foraminifera. Figures of

some of these are given in the annexed woodcut. As this miliolite stone never occurs in the Faluns, or Miocene strata of Brittany and Touraine, it often furnishes the geologist with a useful criterion for distinguishing the detached Eocene and Miocene formations scattered over those and other adjoining provinces. The discovery of the remains of *Palæotherium* and

EOCENE FORAMINIFERA.

Fig. 222. Fig. 223. Fig. 224.



Calcarina rarispina, Desh. *Spirolina stenostoma*, Desh. *Triloculina inflata*, Desh.

a. Natural size. *b*. Magnified.

other mammalia in some of the upper beds of the Calcaire grossier shows that these land animals began to exist before the deposition of the overlying gypseous series had commenced.

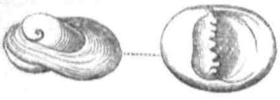
Lower Calcaire grossier, or Glauconie grossière.—The lower part of the Calcaire grossier, which often contains much green earth, is characterised at Auvers, near Pontoise, to the north of Paris, and still more in the environs of Compiègne, by the abundance of nummulites, consisting chiefly of *N. lævigatus*, *N. scabra*, and *N. Lamarcki*, which constitute a large proportion of some of the stony strata, though these same foraminifera are wanting in beds of a similar age in the immediate environs of Paris.

Lower Eocene of the Paris Basin.—There is no exact equivalent of the London clay in this area, and the next strata, in downward succession, to the Calcaire grossier, are the Sables de Cuise.

Sables de Cuise.—These are of considerable thickness, especially at Cuisse-Lamotte, near Compiègne, and other localities in the Soissonnais, about fifty miles N.E. of Paris, from which about 300 species of shells have been obtained, many of them common to the Calcaire grossier and the Bracklesham beds of England, and many peculiar. The *Nummulites planulatus* is very abundant, and the most characteristic shell is the *Nerita conoidea*, Lam., a fossil which has a very wide geographical range; for, as M. d'Archiac remarks, it accom-

panies the Nummulitic formation from Europe to India, having been found in Cutch, near the mouths of the Indus, associated with *Nummulites scabra*. No less than 33 shells of this group are said to be identical with shells of the London clay proper; yet, after visiting Cuisse-Lamotte and other localities of the 'Sables inférieurs' of d'Archiac, I agree with Professor Prestwich[9] that the latter are probably newer than the London clay, and perhaps older than the Bracklesham beds of England.

Fig. 225.



Nerita conoidea, Lam. ½.
Syn. N. *Schmidelliana*, Chemnitz.

Lignites of Soissonnais and Argile plastique.—At the base of the above strata are extensive deposits of sands, with occasional beds of clay used for pottery. Fossil oysters (*Ostrea bellovacina*) abound in some places; and in others there is a mixture of fluviatile shells, such as *Cyrena cuneiformis* (fig. 217), *Melania inquinata* (fig. 218), and others, frequently met with in beds occupying the same position in the Woolwich beds of the London Basin. Layers of lignite are also intercalated.

Sables de Bracheux.—The marine sands called the Sables de Bracheux (a place near Beauvais) are considered by M. Hébert to be older than the Lignites and Plastic clay, and to coincide in age with the Thanet Sands of England. At La Fère, in the department of Aisne, in a deposit of this age, a fossil skull has been found of a quadruped called by Blainville *Arctocyon primævus*, and supposed by him to be related both to the Bear and to the Kinkajou (*Cercoleptes*). This creature appears to be the oldest known tertiary mammifer.

The Conglomerate of Meudon.—In the year 1855, the tibia and femur of a large bird, equalling at least the ostrich in size, were found at Meudon, near Paris, at the base of the Plastic clay. This bird, to which the name of *Gastornis Parisiensis* has been assigned, appears, from the Memoirs of MM. Hébert, Lartet, and Owen, to belong to an extinct genus. Professor Owen refers it to the class of wading land birds rather than to an aquatic species.

That a formation so much explored for economical purposes as the Argile plastique around Paris, and the clays and sands of corresponding age near London, should never have afforded any vestige of a feathered biped previously to the year 1855, shows what diligent search and what skill in osteological interpretation

[9] D'Archiac, Bulletin, tom. x.; and Prestwich, Geol. Quart. Journ. 1847, p. 377.

are required before the existence of birds of remote ages can be established.

Some limestones, sands, and marine conglomerates at Rilly, beneath the Meudon conglomerate, are the lowest members of the French Eocene, and are older than the Thanet Sands, but slightly younger than a remarkable deposit at the base of the Belgian Eocene. The conglomerates rest on the chalk, and their fauna is marine and tertiary in its character.

CHAPTER XVII.

Eocene of Belgium—The Calcaire grossier de Mons—Its fauna—Middle Eocene—Wemmalian, or Upper Eocene—Table of equivalent Eocene strata—Nummulitic formation of Europe, Africa, and Asia—The Flysch—Eocene succession in India—Eocene of United States—Zeuglodont remains—Western territories—Wahsatch—Bridger and Uintah groups.

Belgian Eocene.—As the synchronism of the Belgian, French, and British deposits is given in the table (p. 236), it is only necessary to remark upon the lowest of the deposits—the Calcaire grossier de Mons. This rock is lower than the horizon of the Thanet Sands, and fills a depression in the chalk, being 300 feet thick. Upwards of 400 species of fossils have been obtained from it. Vast numbers of *Gasteropoda, Lamellibranchiata, Bryozoa*, and *Foraminifera* (*Quinqueloculina*), and calcareous *Algæ* are found. There are hardly any fossils in this series which are known as Cretaceous, but very numerous *Cerithia* and *Turritellæ* are of the same species as those of the Middle Eocene of Belgium and the Paris Basin. The alliance is not with those of the Lower Eocene. Hence the Middle Eocene deposits are more or less colonies of the parent area beneath. The Middle Eocene approximates to the English type, and the Upper or Wemmalian series is full of *Nummulites variolarius*.

The flora of Gelinden, which is on the geological horizon of the Thanet Sands of England, contains many species of *Dryophyllum*, a genus somewhat resembling that of the modern American Chestnut Oak. But the flora as a whole has no satisfactory alliance with the Eocene flora of America.

Nummulitic formation of Europe, Asia, &c.—Of all the rocks of the Eocene period, no formations are of such great geographical importance as the Upper and Middle Eocene, or Nummulitic. It appears that of more than fifty species of Nummulites described by D'Archiac, one or two species only are found in other Tertiary formations whether of older or

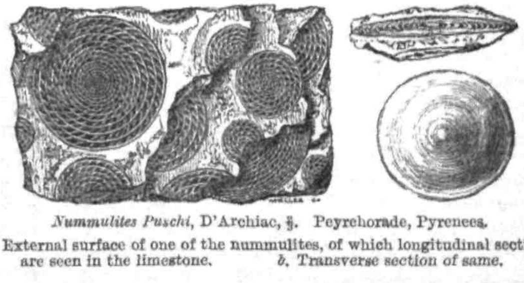
EQUIVALENT EOCENE STRATA OF ENGLAND, PARIS BASIN OF FRANCE, AND BELGIUM.

	England	France (Paris Basin)	Belgium	
UPPER EOCENE	Upper Bagshot Sands Barton Clay	1. { Marine Gypseous series with *Pholadomya Ludensis* Calcaire de Saint-Ouen } 2. Grès de Beauchamp 3. Sables de Guépel 4. Grits with *Nummulites variolarius*	Wemmalian	Sands ferruginous Glauconiferous clay Sands Grits with *Nummulites variolarius*
MIDDLE EOCENE	Bracklesham Beds	Calcaire grossier supérieur } Caillasses Calcaire grossier moyen { Calcaire à *Cérithes* Calcaire à *Orbitolites* and *Miliolites*	Wanting Laekenian	 Couche à Ditrupa et Orbitolites Grit with rolled *Nummulites lævigatus*
	Middle Bagshots	Calcaire grossier inférieur { Couches à *Cerithium giganteum* Couches à *Nummulites lævigatus* Glauconiferous beds Gravel with shark's teeth	Wanting Bruxellian	 Sands with calcareous grits Sands with siliceous grits
LOWER EOCENE	London Clay	Wanting	Paniselian	Sands with *Cardita planicosta* White sands Marls and psammites Gravel or clay
	Oldhaven Beds	Wanting	Ypresian	Sands with *Nummulites planulatus* *Argile de Flandres.*
	Woolwich and Reading Series	Sables de Cuise Lignites du Soissonnais et Argile plastique	Landenian	Sands and lignite of Ostende & Ghent, with *Cyrena cuneiformis* Tuffeau de Lincent
	Thanet Sands	Sables de Bracheux	Heersian	Gelinden marls with plants Sands, with *Cyprina planata*
	Wanting	Conglomerate de Meudon Conglomerate de Rilly Wanting	Calcaire grossier de Mons.	

newer date. *Nummulites intermedius* and *N. garaunsensis*, &c. ascend into the Oligocene, but it seems doubtful whether any species descends to the level of the London clay, still less to the Argile plastique or Woolwich beds. Separate groups of strata are often characterised by distinct species of nummulite; thus *N. variolarius* is found in an upper, *N. lævigatus* in a middle, and *N. planulatus* in a lower zone. The nummulitic limestone of the Swiss Alps rises to more than 10,000 feet above the level of the sea, and attains here and in other mountain-chains a thickness of several thousand feet. It may be said to play a far more conspicuous part than any other Tertiary group in the solid framework of the earth's crust, whether in Europe, Asia, or North Africa. It occurs in Algeria and Morocco, and has been traced from Egypt, where it was largely quarried of old for the building of the Pyramids, into Asia Minor, and across Persia by Bagdad to the mouths of the Indus. It has been observed not only in Cutch, but in the mountain-ranges which separate Sind from Persia, and which form the passes leading to Cabul; and it has been followed still farther eastward into India, as far as Eastern Bengal amongst the Himalayas, and the frontiers of China.

Dr. T. Thomson found Nummulites in Western Thibet at an elevation of no less than 16,500 feet above the level of the sea. One of the species, which I myself found very abundant on the

Fig. 226.



Nummulites Puschi, D'Archiac, ⅔. Peyrehorade, Pyrenees.

a. External surface of one of the nummulites, of which longitudinal sections are seen in the limestone. b. Transverse section of same.

flanks of the Pyrenees, in a compact crystalline marble (fig. 226), is called by M. d'Archiac *Nummulites Puschi*. The same is also very common in rocks of the same age in the Carpathians.

When we have once arrived at the conviction that the nummulitic formation occupies a middle and upper place in the Eocene series, we are struck with the comparatively modern date to which some of the greatest revolutions in the physical geography of Europe, Asia, and Northern Africa must be

referred. All the mountain-chains, such as the Alps, Pyrenees, Carpathians, and Himalayas, into the composition of whose central and loftiest parts the nummulitic strata enter bodily, could have had no such altitude till after the Middle Eocene period. During that period the sea mainly prevailed where these chains now rise, for Nummulites were unquestionably inhabitants of salt water. Before these events, comprising the conversion of a wide area from a sea to a continent, England had been peopled, as I have pointed out (p. 227), by various quadrupeds, by herbivorous pachyderms, by insectivorous bats, and by opossums.

Almost all the volcanoes which preserve any remains of their original form, or from the craters of which lava streams can be traced, are more modern than the Eocene fauna now under consideration.

Sometimes the nummulitic limestone is associated with sandy deposits, and in the Vienna area a deposit called Flysch may be partly of Upper Eocene age. In the southern and south-eastern Alps, the Macigno has the character of the Flysch, and presents fucoids as its only fossils. It overlies conglomerates and calcareous marls, and then comes the main nummulitic limestone.

Eocene and Nummulitic of India.—The succession of strata in Sind and Cutch has been examined, and the Corals and Echinodermata they contain published. The lowest deposits underlie a trap and are called *Cardita Beaumonti* beds. A very fossiliferous deposit, the Ranikot, rests on them, and is covered by the true nummulitic limestone of the Khirthar series, and Oligocene deposits of the Nari group succeed.

Eocene strata in the United States.—In eastern North America the Eocene formations occupy a large area bordering the Atlantic, which increases in breadth and importance as it is traced southwards from Delaware and Maryland to Georgia and Alabama. They also occur in Louisiana and other States both east and west of the valley of the Mississippi. At Claiborne, in Alabama, no less than 400 species of marine shells, with many echinoderms and teeth of fish, characterise one member of this system. Among the shells, the *Cardita planicosta*, before mentioned (fig. 192, p. 219), is in abundance; and this fossil and some others identical with European species, or very nearly allied to them, make it highly probable that the Claiborne beds agree in age with the central or Bracklesham group of England, and with the Calcaire grossier of Paris.[1]

[1] See paper by the Author, Quart. Journ. Geol. Soc. vol. iv. p. 12; and Second Visit to the United States, vol. ii. p. 59.

Higher in the series is a remarkable calcareous rock, made up of Foraminifera, called Orbitoidal limestone.

Above the Orbitoidal limestone is a white limestone, sometimes soft and argillaceous, but in parts very compact and calcareous. It contains several peculiar corals, and a large Nautilus allied to *N. ziczac*; also in its upper bed a gigantic Cetacean, called *Zeuglodon* by Owen.[2]

The colossal bones of this Cetacean are so plentiful in the interior of Clarke County, Alabama, as to be characteristic of the formation. The vertebral column of one skeleton found by Dr. Buckley at a spot visited by me, extended to the length of

Fig. 227.

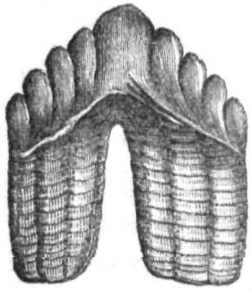
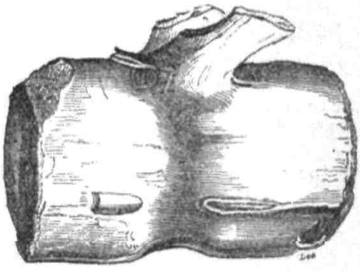


Fig. 228.



Zeuglodon cetoides, Owen.
Basilosaurus, Harlan.

Molar tooth, natural size. Vertebra, reduced.

nearly seventy feet, and not far off, part of another backbone nearly fifty feet long was dug up. I obtained evidence, during a short excursion, of so many localities of this fossil animal within a distance of ten miles, as to lead me to conclude that there must have been at least forty distinct individuals.

Zeuglodon has also been described by Professor H. G. Seeley from the British Eocene.

Eocene of the Western Territories.—There is some difficulty in determining the base of the Eocene series in the Western Territories of the United States in consequence of the antagonism of the mammalian and plant fossils. But there is a limit drawn by the distinguished American palæontologist, Professor Marsh, who writes: 'The line, if line there be, separating the Cretaceous from the Tertiary, must at present be where the Dinosaurs and other Mesozoic vertebrates disappear and are replaced by the Mammals, henceforth the dominant type.'

[2] See Memoir by R. W Gibbes, Journ. of Acad. Nat. Sci. Philad. vol. i. 1847.

The freshwater Eocene deposits are between the Rocky Mountains and the Wahsatch range to the west, and are on the central plateau of the continent. The area was once marine, during the early cretaceous period, and elevation took place; the salt water deposits gave place to freshwater ones, which accumulated in lakes surrounded by a land teeming with life and luxuriant vegetation. The lacustrine deposits are at least two miles thick, and form three groups with different faunas.

The Lower Eocene.—This rests unconformably on the cretaceous, and has been called the Vermilion Creek or Wahsatch group. It contains a well-marked mammalian fauna, containing *Coryphodon*, a Tapir-like animal, with low cerebral characteristics. The occurrence of other species of this genus in Europe at the same geological horizon is very remarkable. A diminutive kind of horse, *Equus eohippus*, of the size of a Fox, and an equally small Tapir, are characteristic of the deposits, as is the genus *Limnohyus*, and the earliest Pig, *Eohyus*. *Dryptodon* belongs to the family *Tillodontia*, which combines the characters of several mammalian groups, such as the ungulates, carnivora, and rodentia. The oldest Squirrel, *Sciuravus*, and the earliest carnivora, *Limnocyon* and *Prototomus*, occur, and the genera *Lemuravus* and *Limnotherium*, which were lemurine animals.

The Middle Eocene.—The Green river and Bridger series are characterised by the presence of *Dinocerata*, a family of gigantic Ungulates. A number of species of *Dinoceras*, *Tinoceras*, and *Uintatherium* lived during the Middle Eocene, and disappeared before the close of the period. They nearly equalled the Elephants in bulk, and the skull had two or three pairs of horns and enormous canine tusks. The brain was exceedingly small. *Orohippus*, a more advanced horse; a Tapir with horns, *Colonocerus*; a huge Tapiroid, *Palæosyops*; *Helohyus*, a Pig with four toes; and *Homocodon*, a crescent-toothed ruminant; and *Tillotherium*, occur. Small rodents of extinct genera and Insectivora were numerous. Carnivora increased in number, and *Limnofelis* was as large as a Lion; *Orocyon* had massive jaws and short teeth; and *Dromocyon* was a large animal. The Lemuroid genera persisted, and *Limnotherium* had affinities with the Marmosets. The oldest Rhinoceros of America was *Orthocynodon* of these beds.

The Upper Eocene.—The Uintah group is characterised by a large Mammal, the *Diplacodon* and an odd-toed Ungulate, *Orohippus*, still lived on, and became extinct during this age. One of the Rhinocerotidæ was *Amynodon*. The crescent-toothed Ungulates are small, and *Eomeryx* is allied to *Hyopotamus* of

Europe, and *Oromeryx* is allied to the Deer, which appeared subsequently. This wonderful Eocene fauna contains no species of *Anoplotherium* or *Palæotherium*, European Eocene forms, or of any Proboscidean, Edentate, or Hollow-horned Ruminant. But the Rhinoceros, Horse, Pig, Deer, and Tapir were clearly foreshadowed. It appears that as the Carnivora increased in numbers, the huge horned animals gradually disappeared.

The Lower Eocene contained *Crocodilia*, Wading birds, and *Unitornis*, a Woodpecker. Large serpents occurred during the Eocene, and were related to the *Boa constrictor*. Lizards were numerous, and the modern Gar-pike and a Dog-fish were represented by closely allied species.

No Nummulitic formations have been found in the New World, but deep marine Eocene deposits occur in the West Indian Islands, with corals.

CHAPTER XVIII.

UPPER CRETACEOUS GROUP.

Lapse of time between Cretaceous and Eocene periods—Classification of Cretaceous formations—Maestricht beds—Pisolitic limestone of France—Chalk of Faxoe—Geographical extent and origin of the White Chalk—Chalk and its analogue on the bed of the Atlantic—Chalk flints—Potstones of Horstead—Vitreous sponges in the Chalk—Isolated blocks of foreign rocks in the white chalk, supposed to be iceborne—Distinctness of mineral character in contemporaneous rocks of the Cretaceous epoch—Fossils of the white chalk—Lower white chalk without flints—Grey chalk—Chalk marl and its fossils—Chloritic marl or Upper Greensand—Coprolite bed near Cambridge—Gault—Flora of the Upper Cretaceous period—Hippurite Limestone—Cretaceous rocks in the United States, and their flora and fauna—Fossil birds with teeth.

We have treated in the preceding chapters of the Tertiary or Cainozoic strata, and have next to speak of the Secondary or Mesozoic formations. The uppermost of these last is called the Chalk or the Cretaceous formation, from *creta*, the Latin name for that remarkable white, earthy limestone which constitutes an upper member of the group in those parts of Europe where it was first studied. The marked difference between the fossils of the tertiary and the Cretaceous formations, has induced many geologists to suspect that a vast lapse of time occurred between the completion of the chalk and the first deposits of the Eocene in Europe. Measured, indeed, by such a standard—that is to say, by the amount of change in the Fauna and Flora of the earth effected in the interval—the time between the

Cretaceous and Eocene may have been as great as that between the Eocene and Recent periods. Several deposits, however, have been met with during the course of the last half century, of an age intermediate between the white chalk and the plastic clays and sands of the Paris and London districts—monuments which have the same kind of interest to a geologist which certain mediæval records excite when we study the history of nations. For both of them throw light on ages of darkness, preceded and followed by others of which the annals are comparatively well known to us. But these newly discovered records do not fill up the wide gap, some of them being closely allied to the Eocene, and others to the Cretaceous type, while none appear as yet to possess a fauna which may entitle them to hold a perfectly transitional place in the great chronological series.

Among the formations alluded to, the Thanet Sands of Prestwich have been sufficiently described in the last chapter, and classed as Lower Eocene, and the Belgian formations, especially the Calcaire grossier de Mons. On the other hand, the Maestricht and Faxoe limestones are very closely connected with the chalk, to which also the Pisolitic limestone of France is referable.

Classification of the Cretaceous Rocks.—The Cretaceous group has generally been divided into an Upper and a Lower series, the Upper called familiarly *the chalk*, and the Lower *the greensand*. But these mineral characters often fail, even when we attempt to follow out the same continuous subdivisions throughout a small portion of the North of Europe, and are valueless when we desire to apply them to more distant regions. It is only by aid of the organic remains which characterise the successive marine subdivisions of the formation in England and France, that we are able to recognise in remote countries, such as the South of Europe or North America and India, the formations which were there, more or less contemporaneously in progress. In the annexed table it will be seen that I have used the term Neocomian for that commonly called 'Lower Greensand;' this latter term being peculiarly objectionable because the green grains are an exception to the rule in many of the members of this group, even in districts where it was first studied and named. M. Alcide D'Orbigny, in his valuable work entitled 'Paléontologie Française,' has adopted new terms for the French subdivisions of the Upper Cretaceous series, and these are now so generally used by foreign writers that the student should endeavour to remember their relation to the English equivalents so far as it is possible to make them agree.

UPPER CRETACEOUS OR CHALK PERIOD.

English subdivisions.	French equivalents.
1. Maestricht Beds, Faxoe Limestone, and Pisolitic Limestone of France.	1. Étage Danien. Wanting in England.
2. Upper White Chalk, with flints.	2. Sénonien.
3. Lower White Chalk, without flints.	3. Turonien, and part of Cénomanien.
4. Chalk Marl.	4. Cénomanien.
5. Chloritic Marl, Cambridge Greensand.	5. Cénomanien.
6. Upper Greensand.	6. Cénomanien.
7. Gault.	7. Albien.

LOWER CRETACEOUS OR NEOCOMIAN.

(Néocomien of the French.)[1]

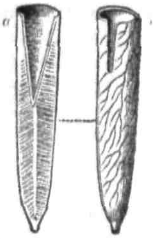
England.	Continent.
1. Upper Neocomian of South East of England, and part of Speeton Clay, Yorkshire.	1. Upper Neocomian.
2. Weald Clay—Middle Speeton and Tealby Beds.	2. Middle Neocomian.
3. Hastings Sands passing into Purbeck beds of the Jurassic series—Lower Speeton Clay.	3. Lower Neocomian.

Maestricht Beds.—On the banks of the Meuse, at Maestricht, reposing on ordinary white chalk with flints, we find an upper calcareous formation about 100 feet thick, the fossils of which are, on the whole, very peculiar, and all distinct from Tertiary species. Some few are of species common to the inferior White Chalk, among which may be mentioned *Belemnitella mucronata* (fig. 229) and *Pecten quadricostatus*, a shell regarded by many as a mere variety of *P. quinquecostatus* (see fig. 270). Besides the Belemnite there are other *genera*, such as *Baculites* and *Hamites*, never found in strata newer than the Cretaceous, but frequently met with in these Maestricht beds. On the

[1] The Lower Cretaceous or Neocomian is also called Néocomien by the French; the name Aptien, formerly adopted by D'Orbigny for the Upper Neocomian, being now but rarely used.

other hand, *Voluta*, *Fasciolaria*, and other genera of univalve shells occur, which are usually met with only in tertiary strata. Or it may be more properly stated that Gasteropoda, which are rare in the English chalk, are not uncommon elsewhere, where the depth at which accumulation took place differed. In the Indian series there are many genera.

Fig. 229.



Belemnitella mucronata, ½. Maestricht, Faxoe, and White Chalk.

a. Osselet or guard, showing vascular impressions on outer surface, with characteristic slit, and mucro.
b. Section of same, showing place of phragmacone.[2]

The upper part of the rock, about 20 feet thick, as seen in St. Peter's Mount, in the suburbs of Maestricht, abounds in corals and Bryozoa, often separable from the matrix ; and these beds are succeeded by a soft yellowish limestone 50 feet thick, extensively quarried from time immemorial for building. The stone below is whiter, and contains occasional nodules of grey chert or chalcedony.

M. Bosquet, with whom I examined this formation (August, 1850), pointed out to me a layer of chalk from two to four inches thick, containing green earth and numerous encrinital stems, which forms the line of demarcation between the strata containing the fossils peculiar to Maestricht and the White Chalk below. The latter is distinguished by regular layers of black flint in nodules, and by shells, such as *Terebratula carnea* (see fig. 246, p. 253), wholly wanting in beds higher than the green band. Some of the organic remains, however, for which St. Peter's Mount is celebrated, occur both above and below that parting layer, and, among others, the great marine reptile called *Mosasaurus*, a saurian supposed to have been 24 feet in length, of which the entire skull and a great part of the skeleton have been found. Such remains are chiefly met with in the soft freestone, the principal member of the Maestricht beds.

The Maestricht chalk consists mainly of more or less friable limestone with a granular texture passing into one of a coarser nature. It does not mark like chalk, and is usually yellowish in colour.

The fragments of shells and fish-teeth are often united by a calcareous cement, and the quantity of fossil remains is vast indeed.[9] *Goniosaurus* and two great Chelonians, a Dinosaur, 20 species of shark ; and some Teleosteans are amongst the vertebrata. Crustacea abound, and amongst the Cephalopoda, be-

[2] For particulars of structure, see p. 292.

sides the genus *Belemnitella*, five species of *Nautilus* are peculiar to the deposit, without including *N. Danicus*. *Baculites*, *Hamites*, and *Scaphites* are scarce, and seven species of *Ammonites* are the last of that great genus. *Gasteropoda* and bivalves abound; and the genera *Crania*, *Thecidium*, *Argiope*, *Magas*, and *Rhynchonella*, and four others are amongst the Brachiopoda. A great number of species of Bryozoa occur, and of Echinoidea also. There are about 30 species of fossil corals, some of which were shallow-water forms, and sponges are not uncommon fossils. Foraminifera of the genera *Rotalia*, *Orbitoides*, and *Polymorphina* are common, and there are a few plant remains, but none of the species are common to a deposit at Aix-la-Chapelle, which will be noticed farther on. The genera are *Sequoia*, *Araucarites*, *Cupressinoxylon*, *Debeyia*, *Thalassocharis*, and *Chondrites*.

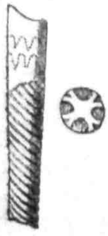
I saw proofs of the previous denudation of the white chalk exhibited in the lower bed of the Maestricht formation in Belgium, about 30 miles S.W. of Maestricht, at the village of Jendrain, where the base of the newer deposit consisted chiefly of a layer of well-rolled, black, chalk-flint pebbles, in the midst of which perfect specimens of *Thecidea papillata* and *Belemnitella mucronata* are embedded. To a geologist accustomed in England to regard rolled pebbles of chalk-flint as a common and distinctive feature of tertiary beds of different ages, it is a new and surprising phenomenon to behold strata made up of such materials and yet to feel no doubt that they were accumulated in a sea in which the belemnite and other Cretaceous mollusca flourished.

Pisolitic limestone of France.—It is met with in the neighbourhood of Paris, and at places north, south, east, and west of that metropolis, as between Vertus and Laversines, Meudon and Montereau. By many able palæontologists the species of its fossils, more than 50 in number, were declared to be more Eocene in their appearance than Cretaceous. M. Hébert found in this formation at Montereau, near Paris, *Pecten quadricostatus*, a well-known Cretaceous species, together with some other fossils common to the Maestricht chalk and to the Baculite limestone of the Cotentin in Normandy. He, therefore, as well as M. Alcide d'Orbigny, who had carefully studied the fossils, came to the opinion that it was an upper member of the Cretaceous group. It is usually in the form of a coarse yellowish or whitish limestone, and the total thickness of the series of beds already known is about 100 feet. Its geographical range, according to M. Hébert, is not less than 45 leagues from east to west, and 35 from north to south. Within these limits it occurs in small patches only, resting unconformably on the White Chalk.

The *Nautilus Danicus* (fig. 231), and two or three other species found in this rock, are frequent in that of Faxoe in Denmark, but as yet no such characteristic genera of the Cretaceous age as *Ammonites*, *Hamites*, *Scaphites*, *Turrilites*, *Baculites*, or *Hippurites* have been met with. Moreover, the great aqueous erosion suffered by the White Chalk, before the Pisolitic limestone was formed, affords an additional indication of the two deposits being widely separated in time.

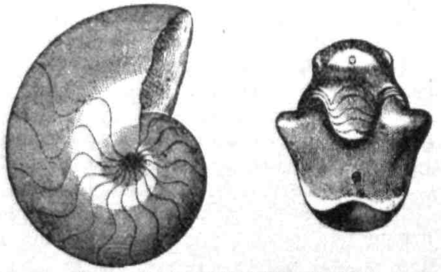
Chalk of Faxoe.—In the island of Seeland, in Denmark, the newest member of the chalk series, seen in the sea-cliffs at Stevensklint resting on white chalk with flints, is a yellow limestone, a portion of which, at Faxoe, where it is used as a building stone, is largely composed of corals. It has been quarried to the depth of more than 40 feet, but its thickness is unknown. The embedded shells are chiefly casts, many of them of univalve mollusca, which are usually very rare in the white chalk of Europe. Thus there are two species of *Cypræa*, one of *Oliva*, two of *Mitra*, four of the genus *Cerithium*, six of *Fusus*, two of *Trochus*, one of *Patella*, one of *Emarginula*, &c., on the whole, more than thirty univalves, spiral or patelliform. At the same time, some of the accompanying bivalve shells, echinoderms, and zoophytes are specifically identical with fossils of the true Cretaceous series. Among the cephalopoda of Faxoe may be

Fig. 230.



Portion of *Baculites Faujasii*, Sow. Maestricht and Faxoe beds and White Chalk.

Fig. 231.



Nautilus Danicus, Schl. Faxoe, Denmark. Maestricht, &c.

mentioned *Baculites Faujasii* (fig. 230), and *Belemnitella mucronata* (fig. 229, p. 244), shells of the White Chalk. The *Nautilus Danicus* (fig. 231) is characteristic of this formation; and it also occurs in France in the Calcaire pisolitique of Laversin (Department of Oise). The claws and entire carapace of a small crab, *Brachyurus rugosus*, are scattered through the Faxoe stone, reminding us of similar crustaceans enclosed in the rocks of modern coral reefs. Some small portions of this coral forma-

tion consist of white earthy chalk. There is no development of these Danien deposits in Great Britain and Ireland, but it is probable that the Norwich chalk is a low member of the group.

British Cretaceous—Upper White Chalk with Flints.

Composition, Extent, and Origin of the White Chalk.—The highest beds of Chalk in England and France consist of a pure white calcareous mass, usually too soft for a building-stone, but sometimes passing into a more solid state. It consists, almost entirely, of carbonate of lime (95–98 per cent.). The stratification is often obscure, except where rendered distinct by interstratified layers of flint, a few inches thick, occasionally in continuous beds, but oftener in nodules, and recurring at intervals generally from two to four feet distant from each other. This Upper Chalk is usually succeeded, in the descending order, by a great mass of White Chalk, without flints, below which comes the Chalk Marl, in which there is a slight admixture of argillaceous matter. The united thickness of the three divisions in the South of England equals, in some places, 1,000 feet.

The area over which the White Chalk preserves a nearly homogeneous aspect, is so vast, that the earlier geologists despaired of discovering any analogous deposits of recent date. Pure chalk, of nearly uniform aspect and composition, is met with in a north-west and south-east direction, from the North of Ireland to the Crimea, a distance of about 1,140 geographical miles; and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles. In Southern Russia, according to Sir R. Murchison, it is sometimes 600 feet thick, and retains the same mineral character as in France and England, with the same fossils, including *Inoceramus Cuvieri*, *Belemnitella mucronata* and *Ostrea vesicularis* (fig. 251, p. 254).

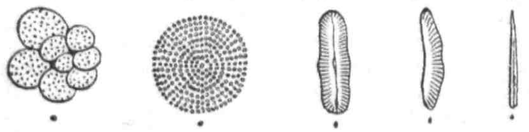
Ordinary white chalk consists of amorphous grains of carbonate of lime, minute pieces of broken-down Foraminifera, *Inocerami*, and other molluscan shells. Almost everything has been broken and jumbled together, and if any perfect Echinoderms, shells and corals are found, they are not in their proper position as a rule.

Sometimes chalk can be found which, when carefully washed with water, yields, under the microscope, besides the worn-down material, minute oval or circular-outlined Coccoliths, and often excellent specimens of *Globigerina bulloides*, and other Foraminifera may be obtained. By soaking chalk in Canada balsam and then cutting sections when dry, and polishing, the Foraminifera

and Coccoliths become more frequently visible than might be expected. The commonest genera of the Foraminifera are *Globigerina*, *Rotalia*, *Textulina*, *Orbitolina*, *Nodosaria*, *Cristellaria*.

Much light has been thrown upon the origin of the White Chalk by the deep soundings made in the North Atlantic, previous to laying down, in 1858, the electric telegraph between Ireland and Newfoundland. The substances brought up were examined by Wallich and subsequently by Huxley, Carpenter, and others. At depths down to 2,000 fathoms, the oaze forming the floor of the ocean was found to be almost entirely composed (more than nineteen-twentieths of the whole) of minute foraminiferal shells of the genus *Globigerina*, especially the species *Globigerina bulloides* (fig. 232). The organic bodies next in quantity were the siliceous shells called *Polycystinæ*, and next to them the siliceous skeletons of plants called *Diatomaceæ* (figs. 233, 234, 235), and occasionally some siliceous spiculæ of sponges (fig. 236) were intermixed. It also contains abundance of the minute

Fig. 232. Fig. 233. Fig. 234. Fig. 235. Fig. 236.



Organic bodies forming the bed of the oaze of the Atlantic at great depths.

Fig. 232. *Globigerina bulloides*. *Calcareous Rhizopod*.
233. *Actinocyclus*.
234. *Pinnularia*. } *Siliceous Diatomaceæ*.
235. *Eunotia bidens*.
236. *Spicula* of sponge. *Siliceous sponge*.

bodies termed Coccoliths, and also Coccospheres, which were discovered by Wallich and are the parent masses of the Coccoliths. They are probably Algæ. They have also been detected as fossil, in chalk.

Dr. Wallich ascertained that 95 per cent. of the mud of a large part of the North Atlantic consists of the shells of *Globigerina*. But Capt. Bullock, R.N., lately brought up from the depth of 2,800 fathoms a white, viscid, chalky mud, wholly devoid of *Globigerinæ*. This mud was perfectly homogeneous in composition, and contained no organic remains visible to the naked eye. Mr. Etheridge, however, has ascertained by microscopical examination, that it is made up of *Coccoliths*, *Discoliths*, and other minute fossils like those of the Chalk. This white mud was dredged up in lat. 20° 19′ N., long. 4° 36′ E., or about midway between Madeira and the Cape of Good Hope.

The recent deep-sea dredgings in the Atlantic, conducted by

Sir C. Wyville Thomson,[3] Dr. Carpenter, Mr. Gwyn Jeffreys, and others, have shown that on the same white ooze there sometimes flourish Mollusca, Crustacea, Corals, and Echinoderms, besides abundance of siliceous sponges, forming on the whole a marine fauna bearing a striking resemblance, in its general character, to that of the ancient chalk.

The origin of the flints, which form such a conspicuous feature of the Upper white chalk of England, has given rise to much speculation. There are several facts to be considered before an explanation should be attempted. Silica in the form of nodules of flint or chalcedony is not restricted to the chalk, but may be found in nearly every great series of sedimentary rocks from the late Tertiary white limestones of Australia to the Silurians. The chalk flints, when in nodular masses, are along very definite lines, which are not always those of original deposition. When tabular in form the flints are often found in joints and fissures which cross the lines of bedding at different angles and reach up to the surface. Some flints (not the tabular masses as a rule) contain relics of organisms, such as Corals, Mollusca, Diatomaceæ, and some sponges enter largely into their composition. The original siliceous organisms may remain and be surrounded by chalcedony, or a calcareous skeleton of a coral, or cast of an echinoderm may be found in the silica and surrounded by a mass of it. Sometimes not a trace of an organism is to be found in the flint. When there are no masses of flint, or in the beds between them, siliceous replacement of the carbonate of lime of mollusca and echinodermata is common. In some chalks, that of Yorkshire, for instance, there has been much replacement of carbonate of lime by silica, a cherty character being produced. In the Antiguan marls the old reef corals are siliceous in some places and semi-siliceous in others, and the replacement of the original carbonate of lime by the silica has been perfect in some instances, and a destructive process has gone on in others. During the replacement of the carbonate of lime of the coral by silica, more or less perfect destruction of the original structures has then occurred, and the former calcareous mass is exhibited as a dark or light-coloured structureless chalcedony.[4] This process took place in the instance of the chalk flints.

The flints and the siliceous bodies are the result of the introduction of silica in solution into the rock, during and after its formation; they are pseudomorphs, or replacements of

[3] An interesting account of the results of the dredging cruises will be found in Sir C. W. Thomson's work, 'The Depths of the Sea.' 1873.

[4] Duncan, Quart. Jour. Geol. Soc. 1864, vol. xx. p. 366.

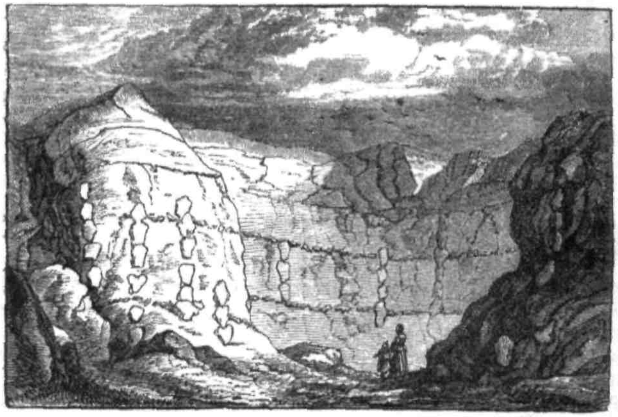
carbonate of lime by silica. The derivation of the silica may be explained by the presence of siliceous organisms and sponges with siliceous skeletons in the deposits, and also by the fact that arenaceous deposits often cover, or have covered, calcareous strata in which flints are now found. The tabular flints are deposits along lines of drainage, and the same may be sometimes the case with the nodular flints. The modern example of the method of formation of flint is not satisfactory. There are Radiolaria, Diatomaceæ, and siliceous Spongida forming deposits on the floor of the ocean. There is the material. It is said that a flinty deposit has been found cementing together foraminifera and other bottom deposits. But no example of the replacement of the calcareous test of any organism by silica has been exhibited. The quantity of silica in the water of the deep sea, taken from off the areas where siliceous deposits occur, is infinitesimal.

In the Southern Ocean the amount of siliceous deposit must be considerable, for Diatomaceæ are found, floating and also on the sea floor, in great quantities. *Globigerina* is found with the siliceous deposit in small quantities ; but the calcareous shells are not silicified. All that can be advanced is, that drainage downwards, when it can happen, may introduce silica in solution from Diatomaceous deposits or from other siliceous deposits, into underlying calcareous strata.

Potstones. Vitreous sponges of the Chalk.—A more difficult enigma is presented by the occurrence of certain huge flints, or potstones, as they are called in Norfolk, occurring singly, or arranged in nearly continuous columns at right angles to the ordinary and horizontal layers of small flints. I visited in the year 1825 an extensive range of quarries then open on the river Bure, near Horstead, about six miles from Norwich, which afforded a continuous section, a quarter of a mile in length, of white chalk, exposed to the depth of about twenty-six feet, and covered by a bed of gravel. The potstones, many of them pear-shaped, were usually about three feet in height and one foot in their transverse diameter, placed in vertical rows, like pillars, at irregular distances from each other, but usually from twenty to thirty feet apart, though sometimes nearer together, as in the sketch (fig. 237). These rows did not terminate downwards in any instance which I could examine, nor upwards, except at the point where they were cut off abruptly by the bed of gravel. On breaking open the potstones, I found an internal cylindrical nucleus of pure chalk, much harder than the ordinary surrounding chalk, and not crumbling to pieces, like it, when exposed to the winter's frost. At the distance of half a mile, the vertical piles of potstones were much farther apart from

each other. Dr. Buckland has described very similar phenomena as characterising the White Chalk on the north coast of

Fig. 237.



From a drawing by Mrs. Gunn.

View of a chalk-pit at Horstead, near Norwich, showing the position of the potstones. (Paramoudra.)

Antrim in Ireland.[5] These pear-shaped masses of flint often resemble in shape and size the large sponges called Neptune's Cups (*Spongia patera*), which grow in the seas of Sumatra; and if we could suppose a series of such gigantic sponges to be separated from each other, like trees in a forest, and the individuals of each successive generation to grow on the exact spot where the parent sponge died and was enveloped in calcareous mud, so that they should become piled one above the other in a vertical column, their growth keeping pace with the accumulation of the enveloping calcareous mud, a counterpart of the phenomena of the Horstead potstones might be obtained.

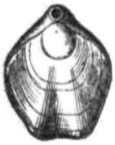
Professor Wyville Thomson, describing the modern soundings in 1869 off the north coast of Scotland, speaks of an arenaceous ooze brought from a depth of about 500 fathoms, and states that at one haul they obtained forty specimens of vitreous sponges buried in the mud. He suggests that the Ventriculites of the chalk were nearly allied to these sponges of the genus *Holtenia*.[6] The Hexactinellid and Lithistid sponges of the deep sea greatly

[5] Geol. Trans. 1st Series, vol. iv. p. 413.

[6] See also Depths of the Sea, 1873, p. 482.

Among the Crinoidea, the *Marsupites* (fig. 242) is a characteristic genus. Among the mollusca, the Cephalopoda are represented by *Ammonites*, *Baculites* (fig. 230, p. 246), and *Belemnitella* (fig. 229, p. 244). Although there are eight or more species of *Ammonites* and six of them peculiar to it, this genus is much less fully represented than in each of the other subdivisions of the Upper Cretaceous group.

Fig. 247.



Terebratula biplicata, Brocchi, ½. Upper Cretaceous.

Fig. 248.

Crania Parisiensis, Duf., ⅔. Inferior, or attached valve. Upper white chalk.

Fig. 249.

Pecten Beaveri, Sow. Reduced to one-third diameter. Lower white chalk, and chalk marl.

Fig. 250.

Lima spinosa, Sow. Syn. *Spondylus spinosus*, ½. Upper white chalk.

Fig. 251.

Ostrea vesicularis. Syn. *Gryphæa convexa*, ½. Upper chalk and Upper greensand.

Fig. 252.

Inoceramus Lamarckii. Syn. *Catillus Lamarckii*, ⅔. White chalk (Dixon's Geol. Sussex, tab. 28, fig. 29).

Among the Brachiopoda in the White Chalk, the *Terebratulæ* are very abundant (see figs. 243, 246, 247). With these are associated some forms of oyster (fig. 251), and other bivalves (figs. 249, 250).

Among the bivalve mollusca, no form marks the Cretaceous era in Europe, America, and India in a more striking manner than the extinct genus *Inoceramus* (*Catillus* of Lam.), (fig. 252),

Fig. 253. Fig. 254.

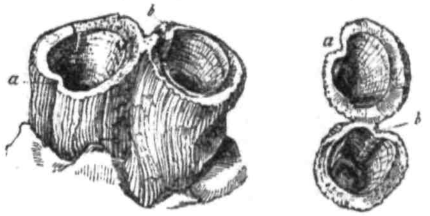


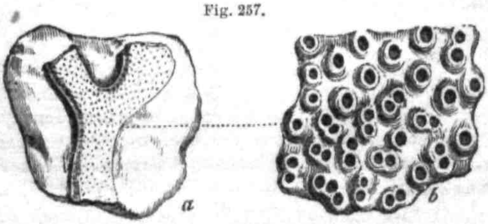
Fig. 255. Fig. 256.

Radiolites Mortoni, Mantell. Houghton, Sussex. White chalk.
Diameter one-seventh nat. size.

Fig. 253. Two individuals deprived of their upper valves, adhering together.
254. Same seen from above.
255. Transverse section of part of the wall of the shell, magnified to show the structure.
256. Vertical section of the same.
On the side where the shell is thinnest, there is one external furrow and corresponding internal ridge, *a*, *b*, figs. 253, 254; but they are usually less prominent than in these figures. The upper or opercular valve is wanting.

the shells of which are distinguished by a fibrous texture, and are often met with in fragments, having probably been extremely friable. *Lima Hoperi* (fig. 271) occurs also.

Fig. 257.



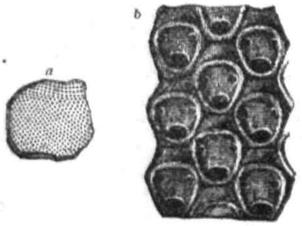
Eschara disticha. White chalk.
a. Natural size. *b*. Portion magnified.

The singular order called *Rudistes*, by Lamarck, hereafter to be mentioned as extremely characteristic of the chalk of Southern Europe, has species (fig. 253) in the White Chalk of England.

The general absence of univalve mollusca in the White Chalk

is very marked. Of Bryozoa there is an abundance, such as *Eschara* and *Escharina* (figs. 257, 258). These and other organic bodies, especially sponges, such as *Ventriculites* (fig. 238), are dispersed indifferently through the soft chalk and hard flint,

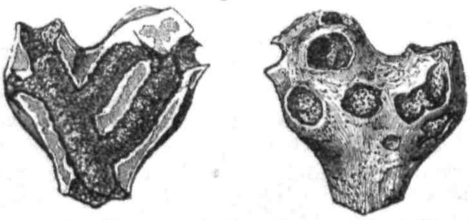
Fig. 258.



Escharina oceani.
a. Natural size.
b. Part of the same magnified.
White chalk.

and some of the flinty nodules owe their irregular forms to enclosed sponges, such as fig. 259, *a*, where the hollows in the exterior are caused by the branches of a sponge (fig. 259, *b*), seen on breaking open the flint.

Fig. 259.

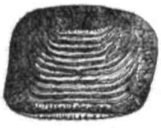


A branching sponge in a flint, from the white chalk.
From the collection of Mr. Bowerbank.

The remains of fishes of the Upper Cretaceous formations consist chiefly of teeth belonging to the shark family, of the genera *Lamna* and *Otodus*, for instance. Some of the genera are common to the Tertiary formations, but many are distinct. To the latter belongs the genus *Ptychodus* (fig. 260), which is allied to the living Port Jackson shark, *Cestraceon Phillippi*, the anterior teeth of which (see fig. 261, *a*) are sharp and cutting, while the posterior or palatal teeth (*b*) are flat. The Teleostean division, to which most of the living bony fishes belong, appears to have commenced in the Cretaceous ages, and it is represented by species of *Beryx*, a genus still existing in the Atlantic and Pacific Oceans. But we meet with no bones of land animals, nor any terrestrial or fluviatile shells, nor any

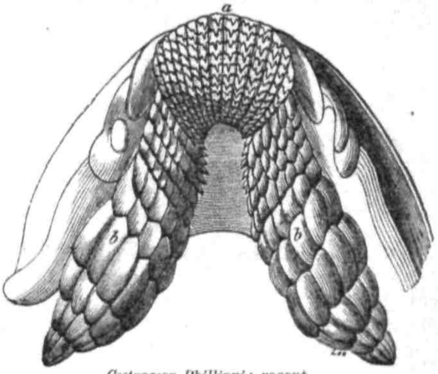
plants, except sea-weeds, and here and there a piece of drift-wood. All the appearances concur in leading us to conclude

Fig. 260.



Palatal tooth of *Ptychodus decurrens*, ⅔. Lower white chalk, Maidstone.

Fig. 261.



Cestracion Phillippi; recent. Port Jackson. Buckland. Bridgwater Treatise, Pl. 27, *d*.

that the White Chalk was the product of an open sea of considerable, but not abyssal, depth.

The existence of turtles and oviparous saurians, and of a *Pterodactylus* or winged lizard, found in the White Chalk of Maidstone, implies, no doubt, some neighbouring land; but a few small islets in mid-ocean, like Ascension, formerly so much frequented by migratory droves of turtle, might perhaps have afforded the required retreat where these creatures laid their eggs in the sand, or from which the flying reptilia may have been blown out to sea. Of the vegetation of such islands we have scarcely any indication, but it consisted partly of cycadaceous plants; for a fragment of one of these was found by Capt. Ibbetson in the Chalk Marl of the Isle of Wight, and is referred by A. Brongniart to *Clathraria Lyelli* (Mantell), a species common to the antecedent Wealden period. The fossil plants, however, of beds corresponding in age to the White Chalk at Aix-la-Chapelle, presently to be described, like the sandy beds of Saxony, before alluded to (p. 252), afford such evidence of land as to prove how vague must be any efforts of ours to restore the geography of that period.

The *Pterodactylus* of the Kentish Chalk, above alluded to, was of gigantic dimensions, measuring 16 feet 6 inches from tip to tip of its outstretched wings. Some of its elongated bones were at first mistaken by able anatomists for those of birds; of which class no osseous remains have as yet been derived from

the White Chalk, although they have been found (as will be seen at p. 260) in the Greensand.

Fig. 262.

Coprolites of fish, from the chalk.

The collector of fossils from the White Chalk was formerly puzzled by meeting with certain bodies which were called arch-cones, which were afterwards recognised by Dr. Buckland to be the excrement of fish (fig. 262). They are composed in great part of phosphate of lime.

The Upper White Chalk with flints is not so united as a perfect series of deposits as may at first sight appear, and there is a distinct arrangement of its fossils in zones. The lowest zone (the Chalk of Dover and Broadstairs type) is that of the Echinoderms called *Micrasters—Micraster cor-testudinarius* and *Micraster cor-anguinum*. Next comes the Margate type, with the zone of *Marsupites ornatus*, *Inoceramus lingua* and *Spongida*. The uppermost beds of the Norwich Chalk belong to the zone of *Belemnitella mucronata*.

Lower White Chalk.—The Lower White Chalk, which is several hundred feet thick, and without flints, has yielded 25 species of *Ammonites*, of which one half are peculiar to it. The genera *Baculites*, *Hamites*, *Scaphites*, *Turrilites*, *Nautilus*, and *Belemnitella*, are also represented. The top of the Chalk without flints is the nodular chalk of Dover and the hard cream-coloured Chalk rock. Below this is a thickness of at least 220 feet of

Fig. 263.

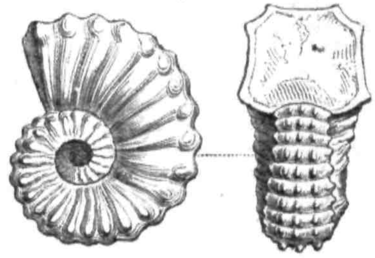
Baculites anceps, Lam. ½. Lower chalk.

Chalk, with some few flint bands near the top. This part is full of fragments of shells, and may be divided into three zones. The zone of *Holaster planus* at the top, *Terebratulina gracilis* next below and overlying the zone of *Inoceramus labiatus*. These zones rest upon the gritty chalk, 32 feet in thickness, and which forms the base of the series. It contains the *Inoceramus* just noticed, and *Echinoconus subrotundus*, &c. The chalk without flints is the equivalent of the continental Turonian, and there is a considerable palæontological break between it and the underlying Cénomanian or Chalk Marl.

There is a fairly well defined bed of yellowish gritty chalk, which may be seen, in some places in the south-east of England, in cliff sections below the Chalk without flints. It contains *Belemnites plenus* and *Radiolites Mortoni*. It merges down-

wards into the Grey Chalk, which is somewhat grey in colour and striped or mottled. Mr. Price states that it attains its full development in the Kentish cliffs, and is 200 feet thick. It contains several zones of fossils, of which that just mentioned may be considered the top. Beneath the zone with *Belemnites plenus* is that of *Holaster subglobosus* (148 feet) and *Discoidea*

Fig. 264.



Ammonites Rhotomagensis, ⅓. Chalk marl. Back and side view.

Fig. 265.

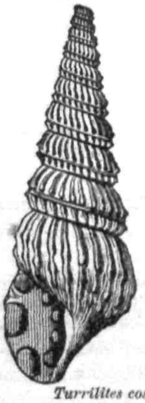


Fig. 266.

Scaphites æqualis, ½.
Chloritic marl and sand,
Dorsetshire.

a

Turrilites costatus, ⅓. Lower chalk and chalk marl.
a. Section, showing the foliated border of the sutures of the chambers.

cylindrica. A lower zone contains *Ammonites Rhotomagensis*, *A. varians*, and *Pecten Beaveri.*

In the neighbourhood of Dunstable, the hard Totternhoe stone passing up into sandy and nearly pure White Chalk is the equivalent of the Grey Chalk, and both overlie the true Chalk Marl.

Chalk marl.—This is an argillaceous chalk, and it forms

with the next division the base of the true Chalk formation. It is seen at Folkestone and in the Isle of Wight, and contains amongst the common fossils *Scaphites æqualis* (fig. 266), *Turrilites costatus* (fig. 265), *Ammonites Mantelli*, and *Lima globosa*.

Chloritic marl.—This yellow or whitish chalky marl contains grains of glauconite, and phosphatic nodules. It contains *Ammonites Mantelli*, *A. varians*, *A. laticlavius*, *Nautilus lævigatus*, *Terebratula biplicata*, &c.

The **Greensand of Cambridge**, a bed about a foot thick, lying on the base of the chalk of Cambridge, is a glauconitic marl with phosphatic nodules, and rolled fossils and erratic blocks. It is the equivalent of the Chloritic marl, is the base of the Chalk marl, and rests unconformably on the Gault, from the denudation of which its rolled fossils have been derived. Numerous reptiles and remains have been found in this deposit belonging to Chelonians, Crocodiles (*Polyptychodon*), Lacertilia (*Mosasaurus*), Dinosauria, many species of *Pterodactylus*, small and large, and species of *Plesiosaurus* and *Ichthyosaurus*. Two species of true birds occur (genus *Enaliornis*), and Professor H. G. Seeley considers them to have been swimming birds.

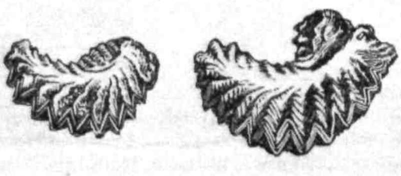
The Red Chalk of Hunstanton is probably of the same geological age as the Cambridge greensand, its colour being due to oxidation of the glauconite.

Upper Greensand.—Sandy strata often greenish in colour, formerly stated to form a distinct formation, are not very readily separable from the Chloritic Marl. But if the separation is real, the formation may be divided into an upper zone with *Pecten*

Fig. 267.

Ostrea columba.
Syn. *Gryphæa Columba*, 1/3.
Upper Greensand.

Fig. 268.



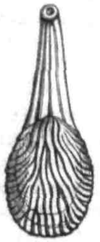
Ostrea carinata, 1/2.
Chalk marl and chloritic sand.

asper, and a lower with *Ammonites rostratus*. But there is a mixture of Chalk Marl, Chloritic Marl, and even of Gault species in this series, so that it is very debateable ground. It is well developed in Devon and Somerset. The Warminster beds contain *Micrabacia coronula*, *Ostrea carinata* (fig. 268), *Pecten asper*, *Terebratula biplicata*, and the Blackdown beds have *Trigonia alæformis*, *Janira quinquecostata*, and *Exogyra conica*.

The development of this series is slight in the Kentish area and to the north.

Among the characteristic mollusca of the Green or Chloritic

Fig. 269.



Terebrirostra lyra, Sow., ½. Upper greensand and marl.

Fig. 270.

Pecten 5-costatus, ½. Lower white chalk and Chloritic series.

Fig. 271.

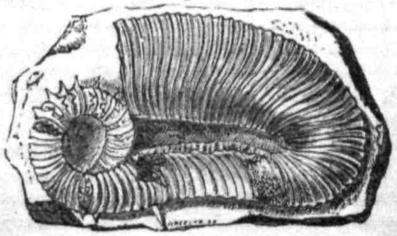
Lima (*Plagiostoma*) *Hoperi*, Sow., ½. Syn. *Lima Hoperi*. White Chalk.

sand may be mentioned *Terebrirostra lyra* (fig. 269), *Pecten quinquecostatus* (fig. 270), and *Ostrea columba* (fig. 267).

The Cephalopoda are abundant : 40 species of *Ammonites* are now known, 10 being peculiar to this subdivision, and the rest common to the beds immediately above or below.

Gault.—The lowest member of the Upper Cretaceous group, usually about 100 feet thick in the S.E. of England, is provin-

Fig. 272.

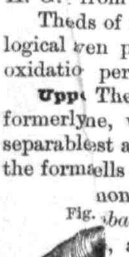


Ancyloceras spinigerum, D'Orb. Syn. *Hamites spiniger*, Sow. Near Folkestone. Gault.

cially termed Gault. It is a stiff dark-blue marl, sometimes intermixed with greensand. Messrs. De Rance and Price have shown that one of the best sections is at Copt Point, near Folkestone, where the upper and lower divisions of the series can be seen. The upper division contains *Ammonites rostratus* *Kingena lima*, *Scaphites æqualis*, *Ammonites cristatus*, and nearly half of its species pass up into the superincumbent beds. The lower division rests on Lower Cretaceous rocks, overlaps

them, and covers the Kimmeridge clay of the Oolitic formation, showing the physical break between the Lower and Upper Cretaceous formations. About one-eighth only of the fossils pass from the Lower into the Upper Gault. The lower division contains *Ammonites auritus*, *A. lautus*, *Solarium moniliferum*, *Ancyloceras spinigerum* (fig. 272), numerous corals and crabs, and species of *Crioceras* and *Hamites*.

Flora of the Upper Cretaceous period.—As the Upper Cretaceous rocks of Europe are, for the most part, of purely marine origin, and formed in deep water usually far from the nearest shore, land-plants of this period, as we might naturally have anticipated, are very rarely met with. In the neighbourhood of Aix-la-Chapelle, however, an important exception ...urs, for there certain white sands and laminated clays, 400 Nu... in thickness, contain the remains of terrestrial plants in a be...utiful state of preservation. These beds are the equivalents (Mo...he White Chalk or Sénonien of D'Orbigny, although the and l...e siliceous sands of the lower beds, and the green grains in specie...pper part of the formation, cause it to differ in mineral cha- H. G.... from our White Chalk. They rest upon Palæozoic rocks. Th...ds of fine clay, with fossil plants, and with seams of lignite, logical ...ven perfect coal, are intercalated. Floating wood, con- oxidatio... perforating shells, such as *Pholas* and *Gastrochæna*, Upp... There are likewise a few beds of a yellowish brown formerly...ne, with marine shells, which enable us to prove that separable...st and highest plant beds belong to one group. Among the form...ells are *Pecten quadricostatus* and several others which ...non to the upper and lower part of the series, and *Tri-* Fig. ...*bata* (D'Orbigny), a shell of the White Chalk; and ..., a form characteristic of the Cretaceous formation, ...nised in 1873 by Professor Hughes in M. Debey's collec- ... the whole, the organic remains and the geological ... the strata prove distinctly, that in the neighbourhood ...hapelle, a gulf of the ancient Cretaceous sea was ...y land composed of Devonian and Carboniferous ...ese rocks consisted of quartzose and schistose beds,



Ostrea colum... Syn. *Gryphæa Co...* Upper Greens...

...which supplied white sand and the other argillaceous ...ver which entered the sea at this point, carrying *asper*, and a l... turbid waters, much drift-wood and the leaves of mixture of Ch...sionally, when the force of the river abated, in this series, ...of the genera *Trigonia*, *Ostrea*, *Pecten*, *Hamites*, developed in ...stablished themselves on the same area, and plants contain *Micrab*...*a* and *Fucus* grew on the bottom. *asper*, *Terebrat*...lants of this member of the Upper Chalk at Aix *Trigonia alæform*...ently collected and studied by Dr. Debey, and

they deserve particular attention. Nearly 100 species are recorded in the lists of the 'Géologie de la Belgique' (M. Mourlon, 1881), by Debey. Of fourteen genera of ferns, three are still existing—namely, *Gleichenia*, now inhabiting the Cape of Good Hope and New Holland; *Lygodium*, now spread extensively through tropical regions, but having some species which live in Japan and North America; and *Asplenium*, a living cosmopolite form. The genus *Pteridoleimma* is represented by no less than 22 species, or nearly one-half of the whole flora of ferns.

Among the phanerogamous plants, the Conifers are abundant, the most common belonging to the genus Sequoia (or Wellingtonia), of which both the cones and branches are preserved. When I visited Aix, I found the silicified wood of this plant very plentifully dispersed through the white sands in the pits near that city. In one silicified trunk 200 rings of annual growth could be counted. The Monocotyledons there, are very peculiar types. No Palms have been recognised with certainty, but a species of *Pandanus*, or Screw-pine, is found. But the number of the Dicotyledonous Angiosperms is the most striking feature in this ancient flora.

Among them we find five species of the oak (*Dryophyllum*), a genus very American in its affinities.

The resemblance of the flora of Aix-la-Chapelle to the tertiary and living floras is considerable, but the angiospermous Dicotyledons did not commence with the Tertiary age, but long before. We can now affirm that these Aix plants flourished before the rich reptilian fauna of the secondary rocks had ceased to exist. The *Ichthyosaurus*, *Pterodactylus*, and *Mosasaurus* were of coeval date with the plant *Dryophyllum*. Speculations have often been hazarded respecting a connection between the rarity of Exogens in the older rocks and a peculiar state of the atmosphere. A denser air, it was suggested, had in earlier times been alike adverse to the well-being of the higher order of flowering plants, and of the quick-breathing animals, such as mammalia and birds, while it was favourable to a cryptogamic and gymnospermous flora, and to a predominance of reptile life. But we now learn that there is no incompatibility in the co-existence of a vegetation like that of the present globe, and some of the most remarkable forms of the extinct reptiles of the age of gymnosperms.

In Bohemia a flora belonging to the base of the upper chalk contains the Dicotyledonous genera *Acer*, *Alnus*, *Salix*, and *Credneria*.

A Cretaceous flora has been discovered in Greenland of Cénomanian age at 70° N.L.; and its genera resemble those of

the Dakota group (p. 267) of the Cretaceous Formation of the Western Territories of the United States. There are Ferns and a great Dicotyledonous assemblage, including many evergreens and conifers.

A second flora, which is probably of Lower Cretaceous age, is remarkable for having only yielded one Dicotyledonous (Angiospermous) species, but numerous *Conifers*, many *Cycads*, and a few *Monocotyledons*. (See p. 281.)

Hippurite limestone.—*Difference between the chalk of the North and South of Europe.*—By the aid of the three tests, superposition, mineral character, and fossils, the geologist has been enabled to refer to the same Cretaceous period, certain rocks in the North and South of Europe, which differ greatly in their fossil contents and in their mineral composition and structure.

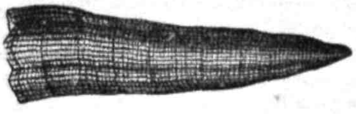
If we attempt to trace the cretaceous deposits from England and France to the countries bordering the Mediterranean, we perceive, in the first place, that in the neighbourhood of London and Paris they form one great continuous mass, the Straits of Dover being a trifling interruption, a valley with chalk cliffs on both sides. We then observe that the main body of the chalk which surrounds Paris, stretches from Tours to near Poitiers (see the annexed map, fig. 273, in which the shaded part represents Chalk).

Fig. 273.

Between Poitiers and La Rochelle, the space marked A on the map separates two regions of chalk. This space is occupied by the Oolite and certain other formations older than the Chalk and Neocomian, and has been supposed by M. E. de Beaumont to have formed an island in the Cretaceous sea. South of this space we again meet with rocks which we at once recognise to be Cretaceous, partly from the chalky matrix and partly from the fossils being very similar to those of the White Chalk of the north; especially certain species of the genera *Spatangus*, *Ananchytes*, *Cidaris*, *Nucula*, *Ostræa*, *Gry-*

phæa (*Exogyra*), *Pecten*, *Lima*, *Trigonia*, *Catillus* (*Inoceramus*), and *Terebratula*.[7] But *Ammonites*, as M. D'Archiac observes,

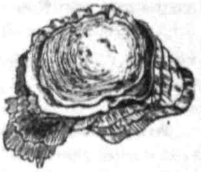
Fig. 274.



a. *Radiolites radiosa*, D'Orb.
b. Upper valve of same.

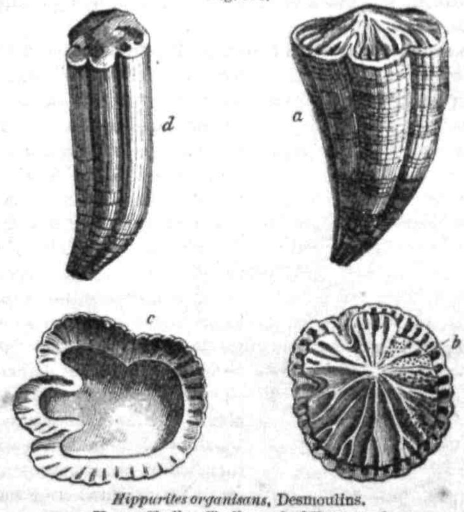
White chalk of France.

Fig. 275.



Radiolites foliaceus, D'Orb.
Syn. *Sphærulites agariciformis*, Blainv.
White chalk of France.

Fig. 276.



Hippurites organisans, Desmoulins.
Upper Chalk: Chalk marl of Pyrenees.[8]

a. Young individual; when full grown they occur in groups adhering laterally to each other.
b. Upper side of the upper valve, showing a reticulated structure in those parts, b, where the external coating is worn off.
c. Upper end or opening of the lower and cylindrical valve.
d. Cast of the interior of the lower conical valve.

of which so many species are met with in the chalk of the North of France, are scarcely ever found in the southern regions, while the genera *Hamites*, *Turrilites*, and *Scaphites* are wanting.

[7] D'Archiac, Sur la Form. Crétacée du S.-O. de la France, Mém. de la Soc. Géol. de France, tom. ii.

[8] D'Orbigny's Paléontologie Française, pl. 533.

On the other hand, certain forms are common in the South which are rare or wholly unknown in the North of France. Among these may be mentioned many *Hippurites*, *Sphærulites*, and other members of an order of mollusca called *Rudistes* by Lamarck, and which is very characteristic of rocks of the Cretaceous era in the South of France, Spain, Sicily, Greece, and other countries bordering the Mediterranean, in Asia and in Jamaica. The species called *Hippurites organisans* (fig. 276) is more abundant than any other in the South of Europe. The cast of the interior *d* is often the only part preserved in many compact marbles of the Upper Cretaceous period. The flutings on the interior of the Hippurite, which are represented on the cast by smooth rounded longitudinal ribs, and in some individuals attain a great size and length, are wholly unlike the markings on the exterior of the shell.

Cretaceous Rocks in the United States.—If we pass to the American continent, we find in the State of New Jersey a series of sandy and argillaceous beds wholly unlike in mineral character to our Upper Cretaceous system; which we can, nevertheless, recognise as referable, palæontologically, to the same division.

That they were about the same age generally as the European Chalk and Neocomian, was the conclusion to which Dr. Morton and Mr. Conrad came after their investigation of the fossils in 1834. The strata consist chiefly of greensand and green marl, with an overlying coral limestone of a pale yellow colour, and the fossils, on the whole, agree most nearly with those of the Upper European series, from the Maestricht beds to the Gault inclusive. I collected sixty shells from the New Jersey deposits in 1841, five of which were identical with European species—*Ostrea larva*, *O. vesicularis*, *Gryphæa costata*, *Pecten quinquecostatus*, *Belemnitella mucronata*. As some of these have the greatest vertical range in Europe, they might be expected more than any others to recur in distant parts of the globe. Even where the species were different, the generic forms, such as *Baculites* and certain sections of *Ammonites*, as also the *Inoceramus* (see fig. 252, p. 254) and other bivalves, have a decidedly Cretaceous aspect. Fifteen out of the sixty shells above alluded to, were regarded by Professor Forbes as good geographical representatives of well-known Cretaceous fossils of Europe. The correspondence, therefore, is not small, when we reflect that the part of the United States where these strata occur is between 3,000 and 4,000 miles distant from the Chalk of Central and Northern Europe, and that there is a difference of ten degrees in the latitude of the places compared on

opposite sides of the Atlantic. Fish of the genera *Lamna*, *Galeus*, and *Carcharodon* are common to New Jersey and the European Cretaceous rocks. So also is the genus *Mosasaurus* among reptiles. *Hadrosaurus* and *Dryptosaurus* occur amongst the Dinosaurs. Professor O. C. Marsh has described several species of birds from the Greensand of New Jersey; and he has discovered in the Upper Cretaceous shale of Kansas a remarkable adult bird about the size of a pigeon, and probably aquatic, to which he gives the name of *Ichthyornis dispar*. This bird approaches the reptilian type in possessing biconcave vertebræ, and well-developed teeth in sockets in both jaws.[9] Another, the *Hesperornis*, was a large aquatic ostrich-like bird, with the teeth in grooves in the jaws.

It appears from the labours of Dr. Newberry and others, that the Cretaceous strata of the United States, east and west of the Appalachians, are characterised by a flora, decidedly analogous to that of Aix-la-Chapelle above mentioned, and therefore having considerable resemblance to the vegetation of the Tertiary and Recent periods.

The Cretaceous rocks are grandly developed in the South-Western States, in Texas, Wyoming, Utah, and Colorado. They are found to the north in Manitoba, and reach to the mouth of the Mackenzie, and into Northern Greenland. In Texas there are limestones with *Hippurites* and *Orbitolites*; but northwards the strata become arenaceous, and were partly deposited in the sea and partly on land. The following are the principal groups. The highest, or Laramie—the Lignitic—is a terrestrial deposit, containing brackish water, and some marine fossils, and a vast flora. The vegetation is remarkable for the number of Dicotyledons, showing that this great section of the vegetable kingdom was in existence before the Tertiary age. The Reptilia found in the deposits are mostly Mesozoic in their affinities, and there are no mammalian remains. *Ammonites* and *Inoceramus* have been found. The deposit is 5,000 feet thick on the Green River.

The second, or Fox Hills group, consists of sandstones, some terrestrial and others marine, with *Belemnitella*, *Nautilus*, *Ammonites*, *Baculites*, and *Mosasaurus*. It is from 3,000 to 4,000 feet thick. Thirdly, the Colorado group, with Cretaceous fossils; and fourthly, the Dakota group, with a remarkable flora.

The flora of the Dakota group (Cénomanian) contains ferns of the genera *Lygodium*, *Sphenopteris*, *Pecopteris*, *Gleichenia*, and *Todea*. Amongst the Gymnosperms, the genera *Pterophyllum*, *Sequoia*, *Araucaria*, *Glyptostrobus*, &c., and *Flabellaria*

[9] American Journ. of Science, vol. v. Feb. 1873.

amongst the palms. There are 167 species of Angiospermous Dicotyledons, of which about one-half are still represented by living species. The order Proteinæ has three genera—*Proteoides*, *Embothrium*, and *Aristolochites*; and amongst the Laurinæ are *Laurus*, *Persea*, *Sassafras*, *Cinnamomum*, *Oreodaphne*; whilst *Magnolia* and *Lyriodendron* are amongst the Polycarpiæ. This flora should be carefully noticed, in order not to be deceived by the statement that Dicotyledons of the above-mentioned genera are necessarily of Tertiary age. The flora would at the present time be normal in a climate like that of the South of Europe of from 35° to 40° N. lat. Probably one-half of the Dicotyledons are allied to recent American forms.

The development of Reptilian life in America during the Cretaceous age was extraordinary. There were very few species of *Ichthyosaurus* in the American area, whilst they were so plentiful in the European Cretaceous strata, and they appear to have been replaced by the *Mosasaurs*. The order *Plesiosauria* was well represented, but mainly by species of genera related to *Pliosaurus*.

The *Mosasauria* ruled supreme in the American Cretaceous seas, and Marsh says that some were 60 feet long and others 10 or 12 feet in length. They were swimming lizards with four paddles. *Crocodilia*, some with biconcave and others with procoelian vertebræ, prevailed during the same age. Amongst the *Pterosauria* was the genus *Pteranodon*, some species having a spread of wings of from 10 to 25 feet; they replaced the *Pterodactyls* of Europe. The American forms had no teeth. Chelonians existed, but the most remarkable Reptilia found, were dwellers on the land, of the group *Dinosauria*. These represented the *Iguanodon* of the Lower Cretaceous of Europe, and the *Dinosaurs* noticed by Seeley in the Maestricht chalk. The Upper Cretaceous Dinosaurs of America are a *Hadrosaurus* of the marine beds and several genera and species, *Agathaumas* being found amidst the relics of Dicotyledonous leaves in the Lignitic series.

CHAPTER XIX.

LOWER CRETACEOUS OR NEOCOMIAN FORMATION.

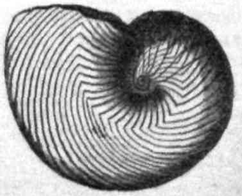
The Lower Cretaceous strata—Upper Neocomian—Folkestone and Hythe beds—Atherfield clay—Similarity of conditions favouring reappearance of species after short intervals—Upper Speeton clay—Middle Neocomian—Tealby series—Middle Speeton clay—Lower Neocomian—Lower Speeton clay—Wealden formation—Freshwater character of the Wealden—Weald clay—Hastings sand—Punfield beds of Purbeck, Dorsetshire—Fossil shells and fish of the Wealden—Area of the Wealden—Flora of the Wealden of England, Belgium, and Greenland—Tithonian strata.

We now come to the Lower Cretaceous formation, which was formerly called Lower Greensand, and for which it will be useful, for reasons before explained (p. 242), to use the term 'Neocomian.'

UPPER NEOCOMIAN.

Folkestone and Hythe beds.—The sands which crop out beneath the Gault in Wiltshire, Surrey, and Sussex are sometimes in the uppermost part pure white, at others of a yellow and ferruginous colour, and some of the beds contain much green matter. At Hythe they contain layers of calcareous matter and chert, and at Maidstone and other parts of Kent the limestone called Kentish Rag is intercalated. This somewhat clayey and calcareous stone forms strata two feet thick, alternating with quartzose sand. The total thickness of these Folkestone, Sandgate, and Hythe beds is less than 300 feet, and the Hythe beds are seen to rest immediately on a grey clay, to which we shall presently allude as the Atherfield clay. Among the fossils of the Hythe beds we may mention *Nautilus plicatus* (fig. 277), *Ancyloceras (Scaphites) gigas* (fig. 278), which has been aptly described as an Ammonite more or less uncoiled; *Trigonia caudata* (fig. 280), *Gervillia anceps* (fig. 279), a bivalve genus allied to Avicula, and *Terebratula sella* (fig. 281). In ferruginous beds of the same age in Wiltshire is found the remarkable shell called *Diceras Lonsdalii* (fig. 282), which abounds in the Upper and Middle Neocomian of Southern Europe.

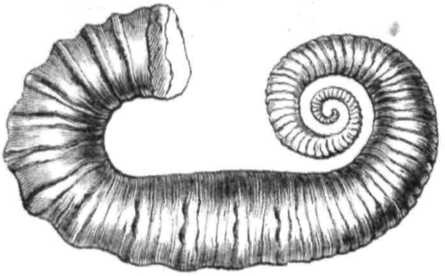
Fig. 277.



Nautilus plicatus, Sow., ½, in Fitton's Monog.

Atherfield clay.—We mentioned before that the Hythe series rests on a grey clay. This clay is only of slight thickness in Kent and Surrey, but acquires great dimensions at Ather-

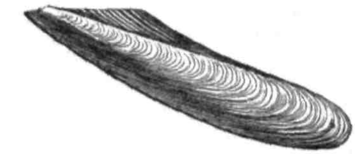
Fig. 278.



Ancyloceras gigas, D'Orb, ⅓.

field, in the Isle of Wight. The difference, indeed, in mineral character and thickness of the Upper Neocomian formation near Folkestone, and the corresponding beds in the south of the Isle

Fig. 279.



Gervillia anceps, Desh., ⅓.
Upper Neocomian, Surrey.

Fig. 280.

Trigonia caudata, Agass., ⅓.
Upper Neocomian.

Fig. 281.

Terebratula sella, Sow., ½.
Upper Neocomian, Hythe.

Fig. 282.

Diceras Lonsdalii, ½. Upper Neocomian, Wilts.
a. The bivalve shell.
b. Cast of one of the valves enlarged.

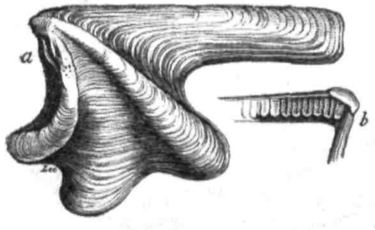
of Wight, about 100 miles distant, is truly remarkable. In the latter place we find no limestone answering to the Kentish Rag, and the entire thickness from the bottom of the Atherfield clay

to the top of the Neocomian, instead of being less than 300 feet as in Kent, is given by the late Professor E. Forbes as 843 feet, which he divides into sixty-three strata, forming three groups. The uppermost of these consists of ferruginous sands; the second of sands and clay; and the third or lowest of a brown clay, abounding in fossils.

Pebbles of quartzose sandstone, jasper, and flinty slate, together with grains of chlorite and mica, occur; and fragments and waterworn fossils of the Oolitic rocks speak plainly, as Mr. Godwin-Austen has shown, of the nature of the pre-existing formations, by the wearing down of which the Neocomian beds were formed. The land, consisting of such rocks, was doubtless submerged before the origin of the White Chalk, a deposit which was formed in a more open and probably deeper sea, and in clearer waters.

Among the shells of the Atherfield clay the most abundant

Fig. 283.



Perna Mulleti, Desh., ½ nat. size.

a. Exterior.
b. Part of hinge-line of upper or right valve.

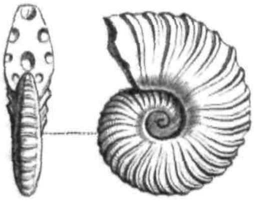
is the large *Perna Mulleti*, of which a reduced figure is here given (fig. 283).

Similarity of conditions causing reappearance of species.—Some species of mollusca and other fossils range through the whole Cretaceous series, while others are confined to particular subdivisions, and Edward Forbes laid down a law which has since been found of very general application in regard to estimating the chronological relations of consecutive strata. Whenever similar conditions, he says, are repeated, the same species reappear, provided too great a lapse of time has not intervened; whereas if the length of the interval has been geologically great, the same genera will reappear represented by distinct species. Changes of depth, or of the mineral nature of the sea-bottom, the presence or absence of lime or of peroxide of iron, the occurrence of a muddy, or a sandy, or a gravelly bottom, are marked by the banishment of certain species and the predominance of others. But these differences of conditions, being mineral, chemical, and local in their nature, have

no necessary connection with the extinction, throughout a large area, of certain animals or plants. When the forms proper to loose sand or soft clay, or to perfectly clear water, or to a sea of moderate or great depth, recur with all the same species, we may infer that the interval of time has been, geologically speaking, small, however dense the mass of matter accumulated. If the genera remain the same, and the species are changed, we have entered upon a new period; and no similarity of climate, or of geographical and local conditions, can then recall the old species which a long series of destructive causes in the animate and inanimate world has gradually annihilated. A species or a variety which has become extinct, never reappears.

Speeton clay.—On the coast beneath the White Chalk of Flamborough Head, in Yorkshire, an argillaceous formation crops out, called the Speeton clay. It is several hundred feet in thickness, and its palæontological relations have been ably worked out by Professor Judd,[1] and he has shown that it is separable into three divisions, the uppermost of which, 150 feet thick, and containing 87 species of mollusca, decidedly belongs to the Atherfield clay and associated strata of Hythe and Folkestone, already described. It is characterised by the *Perna Mulleti* (fig. 283) and *Terebratula sella* (fig. 281), and by *Ammonites Deshayesii* (fig. 284), a well-known Hythe and Atherfield fossil. Remains of skeletons of the genera *Plesiosaurus* and *Teleosaurus* have been obtained from this clay. At the base of this upper division of the Speeton clay there occurs a layer of large Septaria, formerly worked for the manufacture of cement. This bed is crowded with fossils, especially *Ammonites*, some of which are of great size.

Fig. 284.



Ammonites Deshayesii, Leym., ½.
Upper Neocomian.

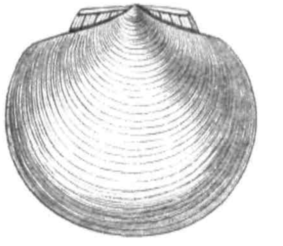
MIDDLE NEOCOMIAN.

Tealby series.—At Tealby, a village in the Lincolnshire Wolds, there are, beneath the White Chalk, some non-fossiliferous ferruginous sands about twenty feet thick, beneath which are beds of clay and limestone about fifty feet thick, with an interesting suite of fossils, among which are *Pecten cinctus* (fig. 285), from 9 to 12 inches in diameter, *Ancyloceras Duvallii* (fig. 286), and some 40 other shells, many of them common to the

[1] Judd, Speeton Clay, Quart. Geol. Journ. vol. xxiv. p. 218.

Middle Speeton clay, about to be mentioned. Professor Judd remarks that as *Ammonites clypeiformis* and *Terebratula hippopus* characterise the Middle Neocomian of the Continent, it is to this

Fig. 285.



Pecten cinctus, Sow. (*P. crassitesta*, Röm.) Middle Neocomian, England; Middle and Lower Neocomian, Germany, ½ nat. size.

Fig. 286.

Ancyloceras (*Crioceras*) *Duvallii*, Leveillé. Middle and Lower Neocomian, ⅓ nat. size.

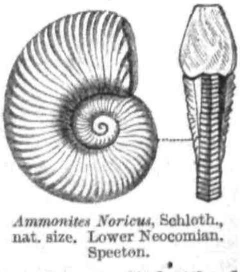
stage that the Tealby series containing the same fossils may be assigned.[2]

The middle division of the Speeton clay, occurring at Speeton below the cement-bed, before alluded to, is 150 feet thick and contains about 39 species of mollusca, half of which are common to the overlying clay. Among the shells are *Ancyloceras Duvallii* (fig. 286) and *Pecten cinctus* (fig. 285).

LOWER NEOCOMIAN.

In the lower division of the Speeton clay, 200 feet thick, 46 species of mollusca have been found, and three divisions, each characterised by its peculiar ammonite, have been noticed by Professor Judd. The central zone is marked by *Ammonites Noricus* (see fig. 287). On the Continent these beds are well known by their corresponding fossils, the Hils clay and conglomerate of the North of Germany agreeing with the Middle and Lower Speeton; the latter of which, with the same mineral characters and fossils as in Yorkshire, is also found in the little island of Heligoland. Yellow limestone, which I have myself seen near

Fig. 287.



Ammonites Noricus, Schloth., nat. size. Lower Neocomian. Speeton.

[2] Judd, Quart. Journ. Geol. Soc. 1867, vol. xxiii. p. 249.

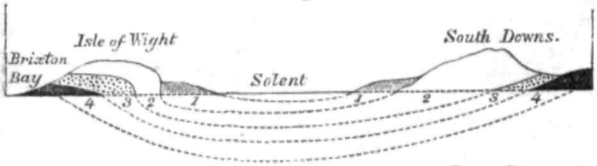
Neuchâtel, in Switzerland, represents the Lower Neocomian at Speeton.

WEALDEN FORMATION.

Beneath the Atherfield clay or Upper Neocomian of the S.E. of England, a freshwater or delta formation is found, called the Wealden, which, although it occupies a small horizontal area in Europe, as compared to the White Chalk and the marine Neocomian beds, is nevertheless of great geological interest, since the embedded remains give us some insight into the nature of the terrestrial fauna and flora of the Lower Cretaceous epoch. The name of Wealden was given to this group because it was first studied in parts of Kent, Surrey, and Sussex, called the Weald; and we are indebted to Dr. Mantell for having shown, in 1822, in his 'Geology of Sussex,' that the whole group was of fluviatile origin. In proof of this he called attention to the entire absence of Ammonites, Belemnites, Brachiopoda, Echinodermata, Corals, and other marine fossils, so characteristic of the Cretaceous rocks above, and of the Oolitic strata below, and to the presence in the Weald of Paludinæ, Melaniæ, Cyrenæ, and various fluviatile shells, as well as the bones of terrestrial reptiles and the trunks and leaves of land-plants.

The evidence of so unexpected a fact as that of a dense mass of purely freshwater origin, underlying a deep-sea deposit (a phenomenon with which we have since become familiar) was received, at first, with no small doubt and incredulity. But the relative position of the beds is unequivocal; the Weald clay being distinctly seen to pass beneath the Atherfield clay in various parts of Surrey, Kent, and Sussex, and to reappear in

W.S.W. Fig. 288. E.N.E.



1. Tertiary. 2. Chalk and Gault. 3. Upper Neocomian (or Lower Greensand).
4. Wealden (Weald Clay and Hastings Sand).

the Isle of Wight at the base of the Cretaceous series, being, no doubt, continuous far beneath the surface, as indicated by the dotted lines in the annexed diagram (fig. 288). They are also found occupying the same relative position below the chalk in the peninsula of Purbeck, where, as we shall see in the sequel, they rest on strata referable to the Upper Oolite.

Weald Clay.—The upper division, or Weald clay, 1,000 feet deep, is, in great part, of freshwater origin, but in its highest portion contains beds of oysters and other marine shells which indicate fluvio-marine conditions. The uppermost beds are not only conformable to the inferior strata of the overlying Neocomian, but are of similar mineral composition. To explain this, we may suppose that, as the delta of a great river was tranquilly subsiding, so as to allow the sea to encroach upon the space previously occupied by fresh water, the river still continued to carry down the same sediment into the sea. In confirmation of this view it may be stated, that the remains of the *Iguanodon Mantelli*, and also species of the genera *Hypsilophodon*, *Pelorosaurus*, *Ornithopsis*, and *Hylæosaurus*, gigantic terrestrial reptiles, belonging to the order Dinosauria, have been discovered near Maidstone, in the overlying Kentish Rag, or marine limestone of the Upper Neocomian, and in the Isle of

Fig. 289.

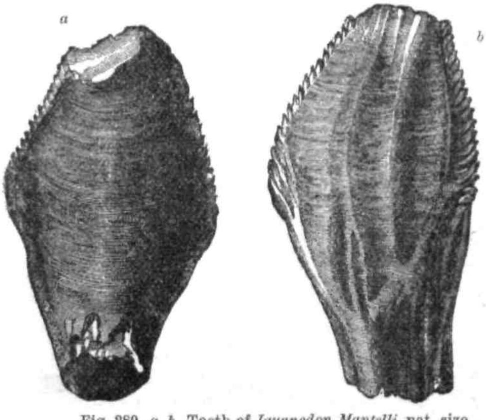


Fig. 290.

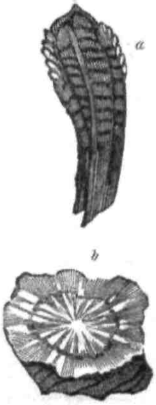


Fig. 289. *a*, *b*. Tooth of *Iguanodon Mantelli*, nat. size.
Fig. 290. *a*. Partially worn tooth of young individual of the same.
b. Crown of tooth in adult, worn down. (Mantell.)

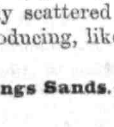
Wight and elsewhere. Hence we may infer that some of the Reptilia which inhabited the country of the great river which formed the Wealden delta, continued to live when part of the district had become submerged beneath the sea. Thus, in our own times, we may suppose the bones of large crocodiles to be frequently entombed in recent freshwater strata in the delta of the Ganges. But if part of that delta should sink down so as to be covered by the sea, marine formations might begin to

accumulate in the same space where freshwater beds had previously been formed; and yet the Ganges might still pour down its turbid waters in the same direction, and carry seaward the carcases of the same species of crocodile, in which case their bones might be included in marine as well as in subjacent freshwater strata.

The Iguanodon, first discovered by Dr. Mantell, was an herbivorous reptile of the order Dinosauria. It was named after the Iguana Lizard, which it in no way resembled except very remotely in the teeth. The Iguanodon's teeth, usually entire, often have a flat ground surface (see fig. 290, *b*) resembling the grinders of herbivorous mammalia. Dr. Mantell computes that the teeth and bones of this species, which passed under his examination during twenty years, must have belonged to no less than seventy-one distinct individuals, varying in age and magnitude from the reptile just burst from the egg, to one of which the femur measured twenty-four inches in circumference. Yet, notwithstanding that the teeth were more numerous than any other bones, it is remarkable that it was not until the relics of all these individuals had been found, that a solitary example of part of a jawbone was obtained. Soon afterwards remains both of the upper and lower jaw were met with in the Hastings beds in Tilgate Forest near Cuckfield. In the same sands at Hastings, Mr. Beckles found large tridactile impressions which it is conjectured were made by the hind feet of this animal, on which it is ascertained that there were only three well-developed toes.

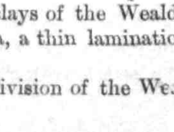
Occasionally bands of limestones called Sussex Marble occur in the Weald clay, almost entirely composed of a species of *Paludina*, closely resembling the common *P. vivipara* of English

Fig. 291.



Cypris spinigera, Fitton.

Fig. 292.



Weald clay, with Cyprides.

rivers. Shells of the *Cypris*, a genus of Crustacea before mentioned (fig. 291) as abounding in lakes and ponds, are also plentifully scattered through the clays of the Wealden, sometimes producing, like plates of mica, a thin lamination (see fig. 292).

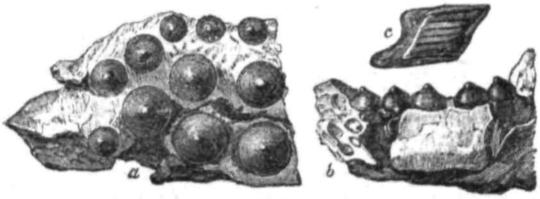
Hastings Sands.—This lower division of the Wealden con-

sists of sand, sandstone, calciferous grit, clay, and shale; the argillaceous strata, notwithstanding the name, predominating somewhat over the arenaceous, as will be seen by reference to the following section, drawn up by Messrs. Drew and Foster, of the Geological Survey of Great Britain:—

	Names of Subordinate Formations.	Mineral Composition of the Strata.	Thickness in Feet.
Hastings Sand.	Tunbridge Wells Sand	Sandstone and loam . .	150
	Wadhurst Clay .	Blue and brown shale and clay with a little calc-grit	100
	Ashdown Sand .	Hard sand with some beds of calc-grit . . .	160
	Ashburnham Beds	Mottled white and red clay with some sandstone .	330

The picturesque scenery of the 'High Rocks' and other places in the neighbourhood of Tunbridge Wells, is caused by the steep natural cliffs, to which a hard bed of white sand, occurring in the upper part of the Tunbridge Wells Sand, mentioned in the above table, gives rise. This bed of 'rock sand' varies in thickness from 25 to 48 feet. Large masses of it, which were by no means hard or capable of making a good building-stone, form, nevertheless, projecting rocks with perpendicular faces, and resist the degrading action of the river because, says Mr. Drew, they present a solid mass without planes of division. The calcareous sandstone and grit of Tilgate Forest, near Cuckfield, in which the remains of the *Iguanodon* and *Hylæosaurus* were first found by Dr. Mantell, constitute an upper member of the

Fig. 293.



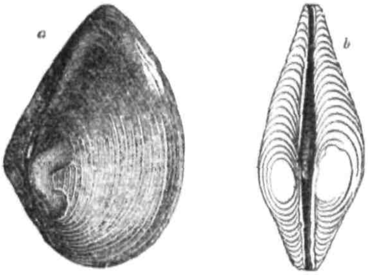
Lepidotus Mantelli, Agass. Wealden.
a. Palate and teeth. *b*. Side view of teeth. *c*. Scale.

Tunbridge Wells Sand, while the 'sand rock' of the Hastings cliffs, about 100 feet thick, is one of the lower members of the same. The reptiles, which are very abundant in this division,

consist partly of marine saurians, among which we find the *Megalosaurus* and *Plesiosaurus*. The *Pterodactylus* is also met with in the same strata, and many remains of Chelonians of the genera *Trionyx* and *Emys*, now confined to tropical regions.

The fishes of the Wealden are chiefly referable to the Ganoid and Placoid orders. Among them the teeth and scales of

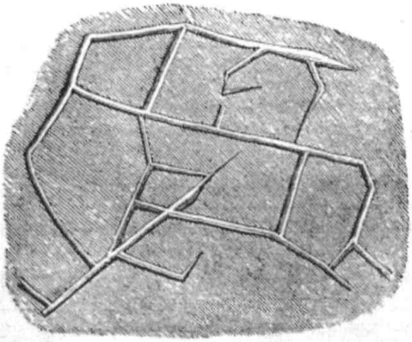
Fig. 294.



Unio Valdensis, Mant., 1/3. Isle of Wight and Dorsetshire; in the lower beds of the Hastings Sands.

Lepidotus are most widely diffused (see fig. 293). These ganoids were allied to the *Lepidosteus*, or Gar-pike, of the American rivers. The whole body was covered with large and very thick rhomboidal scales, having the exposed part coated with enamel. Most of the species of this genus are supposed to have been

Fig. 295.



Underside of slab of sandstone about one yard in diameter. Stammerham, Sussex.

either river-fish, or inhabitants of the sea at the mouth of estuaries.

At different horizons in the Hastings Sand we find again and again slabs of sandstone with strong ripple marks, and between

these slabs are beds of clay many yards thick. In some places, as at Stammerham, near Horsham, there are indications of this clay having been exposed so as to dry and crack before the next layer was thrown down upon it. The open cracks in the clay have served as moulds, of which casts have been taken in relief, and which are, therefore, seen on the lower surface of the sandstone (see fig. 295).

Near the same place a reddish sandstone occurs in which are innumerable traces of a fern, apparently a *Sphenopteris*, the stems and branches of which are disposed as if the plants were standing erect on the spot where they originally grew, the sand having been gently deposited upon and around them; and similar appearances have been remarked in other places in this formation.[3] In the same division also of the Wealden, at Cuckfield, is a bed of gravel or conglomerate, consisting of waterworn pebbles of quartz and jasper, with rolled bones of reptiles. These must have been drifted by a current, probably in water of no great depth.

From such facts we may infer that, notwithstanding the great thickness of this division of the Wealden, the whole of it was a delta deposit, in water of a moderate depth, and often extremely shallow. This idea may seem startling at first, yet such would be the natural consequence of a gradual and continuous sinking of the ground in an estuary or bay, into which a great river discharged its turbid waters. By each foot of subsidence, the fundamental rock would be depressed one foot farther from the surface; but the bay would not be deepened, if newly deposited mud and sand should raise the bottom one foot. On the contrary, such new strata of sand and mud might be frequently laid dry at low water, or overgrown for a season by a vegetation proper to marshes.

Fig. 296.

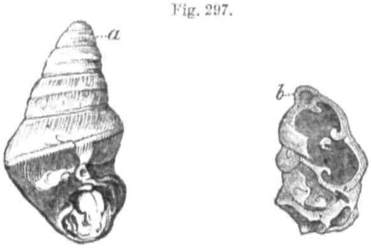
Sphenopteris gracilis, Fitton. From the Hastings Sands near Tunbridge Wells.
a. Portion of the same magnified.

Punfield beds, brackish and marine.—These beds are higher than the Wealden proper. The shells of the Wealden beds belong to the genera *Melanopsis*, *Melania*, *Paludina*, *Cyrena*, *Cyclas*, *Unio* (see fig. 294), and others, which inhabit estuaries, rivers, or lakes; but one bed has been found at Punfield, in Dorsetshire, where the genera *Corbula*, *Mytilus*, and *Ostrea* occur, indicating a brackish state of the water; and in

[3] Mantell, Geol. of S.E. of England, p. 244.

some places this bed becomes purely marine, containing some well-known Neocomian fossils, among which *Ammonites Deshayesii* (fig. 284) may be mentioned.[4] Others are peculiar as British, but very characteristic of the Upper and Middle Neocomian of the North of Spain, and among these the *Vicarya*

Fig. 297.



Vicarya Lujani, De Verneuil,[5] Wealden, Punfield.

a. Nearly perfect shell.
b. Vertical section of smaller specimen, showing continuous ridges, as in *Nerinæa*.

Lujani (fig. 297), a shell allied to *Nerinæa*, is conspicuous. The middle Neocomian beds of Spain, in which this shell abounds, attain at Utrillas a thickness of 530 feet, and contain ten beds of coal, lignite or jet, which are extensively worked.[5]

Area of the Wealden.—In regard to the geographical extent of the Wealden, it cannot be accurately laid down; because so much of it is concealed beneath the newer marine formations. It has been traced about 200 English miles from west to east, from the coast of Dorsetshire to near Boulogne, in France; and 100 miles from north to south. The delta had some 20,000 square miles of area. The Wealdens of Hanover and Westphalia resemble somewhat the English series, but they were the product of another river, and did not belong to one great delta. But it must be remembered that modern deltas are very large. Thus, the delta of the Quorra or Niger, in Africa, stretches into the interior far more than 170 miles, and occupies, it is supposed, a space of more than 300 miles along the coast, thus forming a surface of more than 25,000 square miles, or equal to about one-half of England.[6] Besides, we know not, in such cases, how far the fluviatile sediment and organic remains of the river and the land may be carried out from the coast, and spread over the bed of the sea. I have shown, when treating of the Mississippi, that a more ancient delta, including species of shells such

[4] Judd, Quart. Journ. Geol. Soc. vol. xxvii. 1871, p. 207, *et seq.*

[5] De Verneuil, Foss. de Utrillas.

[6] Fitton, Geol. of Hastings, p. 58, who cites Lander's Travel.

as now inhabit Louisiana, has been upraised, and made to occupy a wide geographical area, while a newer delta is forming; and the possibility of such movements and their effects must not be lost sight of, when we speculate on the origin of the Wealden. On the other hand, the area of the Wealden delta has diminished with denudation.

It may be asked where the continent was placed, from the ruins of which the Wealden strata were derived, and by the drainage of which a great river was fed. The river was from the north-west, and drained a vast area.

Thickness of the Wealden.—In the Weald area itself, between the North and South Downs, freshwater beds to the thickness of 1,600 feet are known. Probably the thickness of the whole Wealden series, as seen in Swanage Bay, cannot be estimated at less than 2,000 feet.

Wealden Flora.—The flora of the Wealden is characterised by a great abundance of Coniferæ, Cycadeæ, and Ferns, the genera *Lonchopteris*, *Sphenopteris*, *Alethopteris*, and *Thujites* being common; and by the absence of leaves and fruits of Dicotyledonous Angiosperms. The discovery in 1855, in the Hastings beds of the Isle of Wight, of Gyrogonites, or spore-vessels of the Chara, was the first example of that genus of plants, so common in the Tertiary strata, being found in a Secondary or Mesozoic rock.

The Belgian Wealden contains the genera *Lonchopteris*, *Pecopteris*, *Alethopteris*, and *Sphenopteris* amongst the ferns, and *Cycadites*; also no less than eight species of *Pinus* of the Coniferæ.

The Arctic flora of Greenland, N. lat. 71°, has already been noticed (p. 264), and the rarity of Dicotyledonous Angiospermous species in it, is in keeping with the nature of other Lower Cretaceous flora.

A mild, warm, temperate climate then extended far towards the Pole, and a sub-tropical climate probably prevailed in the present temperate latitudes.

Tithonian.—In Western France, the Alps, the Carpathians, Northern Italy, and the Apennines, an extensive series of rocks has been described by Continental geologists under the name of Tithonian. These beds, which are without any marine equivalent in this country, appear completely to bridge over the interval between the Neocomian and the Oolites. They may, perhaps, as suggested by Professor Judd, be of the same age as part of the Wealden series. *Terebratula diphya* is a common fossil.

It is very probable that the deposition of the Wealden

commenced before the close of the Purbeck period about to be considered, and continued during the Tithonian and during the accumulation of the marine Lower and Middle Neocomian, and that it terminated at the commencement of the Upper Neocomian.

CHAPTER XX.

JURASSIC GROUP—PURBECK BEDS AND OOLITES.

The Purbeck beds a member of the Jurassic group—Subdivisions of that group—Physical geography of the Oolites in England and France—Upper Oolite—Purbeck beds—New genera of fossil mammalia in the Middle Purbeck of Dorsetshire—Dirt-bed or ancient soil—Fossils of the Purbeck beds—Portland stone and fossils—Kimmeridge clay—Lithographic stone of Solenhofen—Archæopteryx—Middle Oolite—Coral rag—Nerinæa limestone—Oxford clay, Ammonites and Belemnites—Kelloway rock—Lower, or Bath Oolite—Oolite and Bradford clay—Stonesfield slate—Fossil mammalia—Plants of the Oolite—Fuller's earth—Inferior Oolite and fossils—Northamptonshire slates—Yorkshire Oolitic coal-field—Brora coal—Palæontological relations of the several subdivisions of the Oolitic group—The Oolites of Europe and Asia, Australia.

Classification of the Oolites.—Immediately below the Hastings Sands we find in Dorsetshire another remarkable formation, called the *Purbeck*, because it was first studied in the sea-cliffs of the Peninsula of Purbeck in that county. These beds are for the most part of freshwater origin; but the organic remains of some few intercalated beds are marine, and show that the Purbeck series has a closer affinity to the Oolitic group, of which it may be considered as the newest or uppermost member.

In England generally, and in the greater part of Europe, both the Wealden and Purbeck beds are wanting, and the marine Cretaceous group is followed immediately, in the descending order, by another series called the Jurassic. In this term, the formations commonly designated as 'the Oolite and Lias' are included, both being found in the Jura Mountains. The Oolite was so named because, in the countries where it was first examined, the limestones belonging to it had an oolitic structure (see p. 12). These Oolitic rocks occupy in England a zone nearly thirty miles in average breadth, which extends across the island, from Yorkshire in the north-east to Dorsetshire in the south-west. Their mineral characters are not uniform throughout this region; but the following are the names of the principal subdivisions observed in the central and south-eastern parts of England:—

OOLITES.

Upper.	*a.* Purbeck beds. *b.* Portland oolite (stone) and sand. *c.* Kimmeridge clay.
Middle.	*d.* Coral rag. *e.* Oxford clay, and Kelloway rock.
Lower.	*f.* Cornbrash and Forest marble. *g.* Great Oolite and Stonesfield slate. *h.* Fuller's earth. *i.* Inferior Oolite.

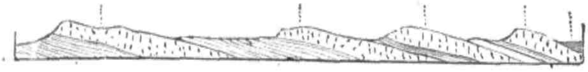
The Upper Oolitic system of the above table, has usually the Kimmeridge clay for its base; the Middle Oolitic system, the Oxford clay. The Lower system rests upon the Lias, an argillo-calcareous formation, which forms the lowest member of the Jurassic system, and which will be treated of in the next chapter. Many of these subdivisions are distinguished by peculiar organic remains; and, though varying in thickness, may be traced in certain directions for great distances, especially if we compare the part of England to which the above-mentioned type refers, with the north-east of France and the Jura Mountains adjoining. In that country, distant above 400 geographical miles, the analogy to the accepted English type, notwithstanding the thinness or occasional absence of the clays, is more perfect than in Yorkshire or Normandy.

Physical Geography.—The alternation, on a grand scale, of distinct formations of clay and limestone has caused the Oolitic and Liassic series to give rise to some marked features in the physical outline of parts of England and France. Wide valleys can usually be traced throughout the long bands of country where the argillaceous strata crop out; and between these valleys the limestones are observed, forming ranges of hills or more elevated grounds. These ranges terminate abruptly on the side on which the several clays rise up from beneath the calcareous strata.

The annexed cut will give the reader an idea of the configuration of the surface now alluded to, such as may be seen in passing from London to Cheltenham, or in other parallel lines from east to west, in the southern part of England. It has been necessary, however, in this drawing, greatly to exaggerate the inclination of the beds, and the height of the several formations, as compared to their horizontal extent. It will be remarked that the lines of steep slope, or escarpment, face towards the west in the great calcareous eminences formed by the Chalk and the Upper, Middle, and Lower Oolites; and at

the base of which we have respectively the Gault, Kimmeridge clay, Oxford clay, and Lias. This last forms, generally, a broad vale at the foot of the escarpment of Inferior Oolite; but where

Fig. 298.



it acquires considerable thickness, and contains solid beds of marlstone, it occupies the lower part of the escarpment.

The external outline of the country which the geologist observes in travelling eastward from Paris to Metz, is precisely analogous, and is caused by a similar succession of rocks intervening between the tertiary strata and the Lias; with this difference, however, that the escarpments of Chalk, and Upper, Middle, and Lower Oolites face towards the east instead of the west. It is evident, therefore, that denuding agents have acted similarly, over an area several hundred miles in diameter, removing the softer clays more extensively than the limestones, and causing these last to form steep slopes or escarpments wherever the harder calcareous rock was based upon a more yielding and destructible formation.

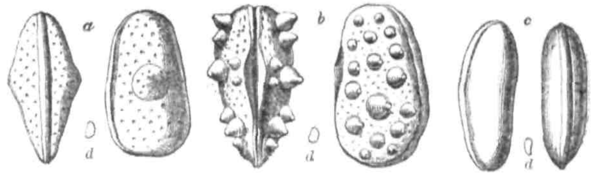
UPPER OOLITE.

Purbeck beds.—These strata, which we class as the uppermost member of the Oolite, are of limited geographical extent in Europe, but they acquire importance when we consider the succession of three distinct sets of fossil remains which they contain. Such repeated changes in organic life must have reference to the history of a vast lapse of ages. The Purbeck beds are finely exposed to view in Durdlestone Bay, near Swanage, Dorsetshire, and at Lulworth Cove and the neighbouring bays between Weymouth and Swanage. At Meup's Bay, in particular, Professor E. Forbes examined minutely, in 1850, the organic remains of this group, displayed in a continuous sea-cliff section; and it appears from his researches that the Upper, Middle, and Lower Purbecks are each marked by peculiar species of organic remains, these again being different, so far as a comparison has yet been instituted, from the fossils of the overlying Hastings Sands and Weald Clay.

Upper Purbeck.—The highest of the three divisions is purely

freshwater, the strata, about fifty feet in thickness, containing shells of the existing genera *Paludina*, *Physa*, *Limnæa*, *Planorbis*, *Valvata*, *Cyclas*, *Unio*, with *Cyprides* and fish. All the species

Fig. 299.



Cyprides from the Upper Purbecks.

a. *Cypris gibbosa*, E. Forbes.
b. *Cypris tuberculata*, E. Forbes.
c. *Cypris leguminella*, E. Forbes.
d. Nat. size.

seem peculiar, and among these the *Cyprides* are very abundant and characteristic. (See fig. 299, *a*, *b*, *c*.)

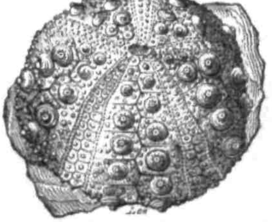
The freshwater limestone called 'Purbeck Marble,' formerly much used in ornamental architecture in the old English cathedrals of the southern counties, is exclusively procured from this division.

Middle Purbeck.—Next in succession is the Middle Purbeck, about thirty feet thick, the uppermost part of which consists of freshwater limestone, with cyprides, turtles, and fish of different species from those in the preceding strata. Below the limestone are brackish-water beds full of *Cyrena*, and traversed by bands abounding in *Corbula* and *Melania*. These are based on a purely marine deposit, with *Pecten*, *Modiola*, *Avicula*, and

Fig. 300.

Ostrea distorta, Sow., nat. size. Cinder-bed, Middle Purbeck.

Fig. 301.



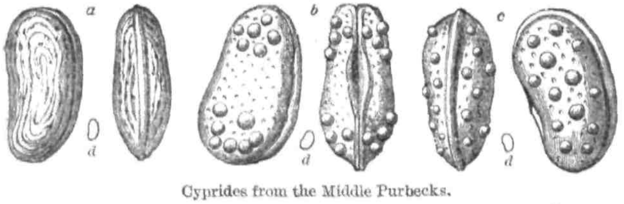
Hemicidaris Purbeckensis, E. Forbes, nat. size. Middle Purbeck.

Thracia. Below this, again, come limestones and shales, partly of brackish and partly of freshwater origin, in which many fish, especially species of *Lepidotus* and *Microdon radiatus*, are found, and a crocodilian reptile named *Macrorhynchus*. Among the

molluscs, a remarkable ribbed *Melania*, of the sub-genus *Chilina*, occurs.

Immediately below is a great and conspicuous stratum, twelve feet thick, formed of a vast accumulation of shells of *Ostrea distorta* (fig. 300), long familiar to geologists under the local name of 'Cinder-bed.' In the uppermost part of this bed Professor Forbes discovered a species of *Hemicidaris* (fig. 301), a genus characteristic of the Oolitic period. It was accompanied by a species of *Perna*, a secondary and tertiary genus. (See fig. 283.) Below the Cinder-bed, freshwater strata are again seen, filled in many places with species of *Cypris* (fig. 302, *a*, *b*, *c*), and with *Valvata*, *Paludina*, *Planorbis*, *Limnæa*, *Physa* (fig. 303), and *Cyclas*, all different from any occurring higher in the series. It will be seen that *Cypris fasciculata* (fig. 302, *b*) has tubercles at the ends only of

Fig. 302.

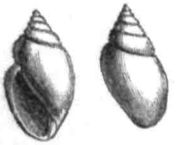


Cyprides from the Middle Purbecks.

a. Cypris striato-punctata, E. Forbes.
b. Cypris fasciculata, E. Forbes.
c. Cypris granulata, Sow.
d. Nat. size.

each valve, a character by which it can be immediately recognised. In fact, these minute crustaceans, almost as frequent in some of the shales as plates of mica in a micaceous sandstone, enable geologists at once to identify the Middle Purbeck in places far from the Dorsetshire cliffs, as, for example, in the Vale of Wardour, in Wiltshire. Thick beds of chert occur in the Middle Purbeck filled with mollusca and *Cyprides* of the genera already enumerated, in a beautiful state of preservation, often converted into chalcedony. Among these Professor Forbes met with *Gyrogonites* (the spore-vessels of *Chara*), plants never before discovered in rocks older than the Eocene. About twenty feet below the 'Cinder-bed' is a stratum two or three inches thick, in which the fossil mammalia presently to be mentioned occur; and beneath this is a thin band of greenish shales, with marine shells and

Fig. 303.



Physa Bristovii, E. Forbes. Middle Purbeck.

impressions of leaves like those of a large *Zostera*; it forms the base of the Middle Purbeck.

Fossil Mammalia of the Middle Purbeck.—In 1852,[1] after alluding to the discovery of numerous insects and air-breathing mollusca in the Purbeck strata, I remarked that, although no mammalia had then been found, 'it was too soon to infer their non-existence from mere negative evidence.' Only two years after this remark was in print, Mr. W. R. Brodie found in the Middle Purbeck, about twenty feet below the 'Cinder-bed,' in the thin stratum above alluded to, in Durdlestone Bay, portions of several small jaws with teeth, which Professor Owen recognised as belonging to a small marsupial of insectivorous habit, more closely allied in its dentition to the *Amphitherium* of an earlier Oolitic age (p. 306) than to any existing type. He named the form *Spalacotherium*, and four years later (in 1856) the remains of several other species of warm-blooded marsupials were exhumed by Mr. S. H. Beckles, F.R.S., from the same thin bed of marl, and also many reptiles, several insects, and some freshwater shells of the genera *Paludina*, *Planorbis*, and *Cyclas* were found.

Mr. Beckles has thoroughly explored the thin stratum in the suburbs of Swanage, and he has brought to light from an area forty feet long and ten wide, and from a layer the average thickness of which was only five inches, portions of the skeletons of six new species of marsupial mammalia as interpreted by Dr. Falconer, who first examined them. Before these interesting inquiries were brought to a close, the joint labours of Professor Owen and Dr. Falconer had made it clear that twelve or more species of marsupial mammalia characterised this portion of the Middle Purbeck, most of them insectivorous in habit and all small. Owen has now raised the number of species to twenty-five, referable to eleven genera.[2] *Spalacotherium*, *Triconodon*, *Peralestes*, *Peramus*, and *Plagiaulax* are examples. While the majority had the character of insectivorous marsupials, Dr. Falconer selected one as differing widely from the rest—namely, *Plagiaulax Becklesii*—and pointed out that in certain characters it was allied to the living Kangaroo-rat, or *Hypsiprymnus*, ten species of which now inhabit the prairies and scrub-jungle of Australia, feeding on plants and gnawing scratched-up roots. A striking peculiarity of their dentition, one in which they differ from all other quadrupeds, consists in their having a single large pre-molar, the enamel of which is furrowed with vertical grooves, usually seven in number.

[1] Elements of Geology, 4th edition.
[2] Monograph, Palæontological Society, 1871.

The largest pre-molar (see fig. 305) in the fossil genus exhibits in a like manner seven parallel grooves, producing by their ter-

Fig. 304.

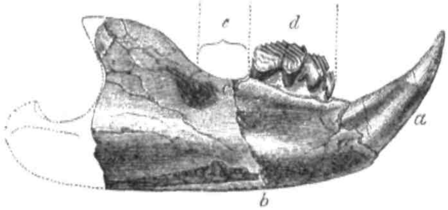
Pre-molar of the recent Australian *Hypsiprymnus Gaimardi*, showing 7 grooves at right angles to the length of the jaw, magnified 3½ diameters.

Fig. 305.

Third and largest pre-molar (lower jaw) of *Plagiaulax Becklesii*, magnified 5½ diameters, showing 7 diagonal grooves.

mination a similar serrated edge in the crown ; but their direction is diagonal—a distinction, says Dr. Falconer, which is 'trivial, not typical.' As these oblique furrows form so marked a character of the majority of the teeth, Dr. Falconer gave to the fossil the generic name of *Plagiaulax*. The shape and relative size of the

Fig. 306.



Plagiaulax Becklesii, Falconer. Middle Purbeck.
Right ramus of lower jaw, magnified two diameters.

a. Incisor. *b*, *c*. Line of vertical fracture behind the pre-molars. *d*. Three pre-molars, the third and last (much larger than the other two taken together) being divided by a crack. *e*. Sockets of two missing molars.

incisor, *a*, fig. 306, exhibit a no less striking similarity to *Hypsiprymnus*. Nevertheless, the more sudden upward curve of this incisor, as well as other characters of the jaw, indicate a great deviation in the form of *Plagiaulax* from that of the living Kangaroo-rat.

There are two fossil specimens of lower jaws of this genus evidently referable to two distinct species extremely unequal in size and otherwise distinguishable. The *Plagiaulax Becklesii* (fig. 306) was about as big as the English squirrel or the flying phalanger of Australia (*Petaurus Australis*, Waterhouse). The smaller fossil, having only half the linear dimensions of the other, was probably only 1-12th of its bulk. It is of peculiar geological interest, because, as shown by Dr. Falconer, its two

back molars bear a decided resemblance to those of the Triassic *Microlestes*, the most ancient of known mammalia, of which an account will be given further on.

Up to 1857 all the mammalian remains discovered in secondary rocks had consisted solely of single branches of the lower jaw, but in that year Mr. Beckles obtained the upper portion of a skull, and on the same slab, the lower jaw of another quadruped with eight molars, a large canine, and a broad and thick incisor. It has been named *Triconodon* from its three-coned teeth, and is supposed to have been a small insectivorous marsupial, about the size of a hedgehog. Other jaws have since been found, indicating a larger species of the same genus.

To the largest of these Professor Owen has given the name of *Triconodon major*. It was a carnivorous marsupial, rather larger than the Pole-cat, and equalling probably in size the *Dasyurus maugei* of Australia.[5]

Between forty and fifty mandibles or sides of lower jaws with teeth, have been found in the Purbecks; only five maxillaries, together with one portion of a separate cranium, occur at Stonesfield in an earlier deposit (p. 305), and it is remarkable that with these there were no examples in Purbeck of an entire skeleton, nor of any considerable number of bones in juxtaposition. Detached bones, often much decomposed, and fragments of others, apparently mammalian, have been found; but if all of them were restored, they would scarcely suffice to complete the five skeletons to which the five upper maxillaries above alluded to belonged. As the average number of pieces in each mammalian skeleton is about 250, there must be many thousands of missing bones; and when we endeavour to account for their absence, we are almost tempted to indulge in speculations like those once suggested to me by Dr. Buckland, when he tried to solve the enigma in reference to Stonesfield :—'The corpses,' he said, 'of drowned animals, when they float in a river, distended by gases during putrefaction, have often their lower jaw hanging loose, and sometimes it has dropped off. The rest of the body may then be drifted elsewhere, and sometimes may be swallowed entire by a predaceous reptile or fish, such as an *Ichthyosaurus* or a Shark.'

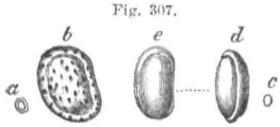
We may safely conclude that all the species lived together in the same region, and in all likelihood they constituted a mere fraction of the mammalia which inhabited the lands drained by one river and its tributaries. They afford the first positive proof as yet obtained, of the co-existence of a varied fauna of the lowest class of mammalia with that ample

[5] Owen, Fossil Mammalia of the Purbeck, Palæon. Soc. 1871.

development of reptilian life which marks all the periods from the Trias to the Lower Cretaceous inclusive, and with a Gymnospermous Dicotyledonous flora, in which Cycads and Conifers predominated over all kinds of plants, except the Ferns. Sir R. Owen has noticed that small dwarf Crocodilia, of the genera *Nannosuchus* and *Theriosuchus*, lived with and possibly upon the diminutive marsupials.

Lower Purbeck.—Beneath the thin marine band mentioned at p. 285 as the base of the Middle Purbeck some purely freshwater marls occur, containing species of *Cypris* (fig. 307 *a*, *c*), *Valvata*, and *Limnæa*, different from those of the Middle Purbeck. This is the beginning of the inferior division, which is about 80 feet thick. Below the marls at Meup's Bay, more than 30 feet of brackish-water strata are seen, abounding in a species of *Serpula*, allied to, if not identical with, *Serpula coacervites*, found in beds of the same age in Hanover. There are also shells of the genus *Rissoa* (of the subgenus *Hydrobia*), and a little *Cardium* of the subgenus *Protocardium*, in these beds, together with *Cypris*. Some of the Cypris-bearing shales are strangely contorted and broken up, at the west end of the Isle of Purbeck. The great dirt-bed or vegetable soil containing the roots and stools of *Cycadeæ*, which I shall presently describe, underlies these marls, and rests upon the lowest freshwater limestone, a rock about eight feet thick, containing *Cyclas*, *Valvata*, and *Limnæa*, of the same species as those of the uppermost part of the Lower Purbeck, or above the dirt-bed. The freshwater limestone in its turn rests upon the top beds of the Portland stone.

Fig. 307.



Cyprides from the Lower Purbeck.
a. *Cypris Purbeckensis*, Forbes.
b. Same magnified.
c. *Cypris punctata*, Forbes.
d, *e*. Two views magnified of the same.

Dirt-bed or ancient surface soil.—A stratum called by quarrymen 'the dirt,' or 'black dirt,' was evidently an ancient vegetable soil. It is from 12 to 18 inches thick, is of a dark brown or black colour, and contains a large proportion of earthy lignite. Through it are dispersed rounded and sub-angular fragments of stone, from 3 to 9 inches in diameter, in such numbers that it almost deserves the name of gravel.

Many silicified trunks of coniferous trees, and the remains of plants allied to *Zamia* and *Cycas*, are buried in this dirt-bed, and must have become fossil on the spots where they grew. The stumps of the trees stand erect for a height of from one to three feet, and even in one instance to six feet, with their roots

attached to the soil, at about the same distances from one another as the trees in a modern forest. The carbonaceous matter is most abundant immediately around the stumps, and round the remains of fossil *Cycadeæ*.

The fragments of the prostrate trees are rarely more than three or four feet in length; but, by joining many of them together, trunks have been restored, having a length from the root to the branches of from 20 to 23 feet, the stems being undivided for 17 or 20 feet, and then forked. The diameter of these near the root is usually about one foot, but I measured one in 1866, which was 3½ feet in diameter; it was said by the quarrymen, to be unusually large. Root-shaped cavities were observed by Professor Henslow to descend from the bottom of the dirt-bed into the subjacent freshwater stone, which, though now solid, must have been in a soft and penetrable state when the trees

Fig. 308.

Section in Isle of Portland, Dorset. (Buckland and De la Beche.)

grew. The thin layers of calcareous shale (fig. 308) were evidently deposited tranquilly, and would have been horizontal, but for the protrusion of the stumps of the trees, around the top of each of which they form hemispherical concretions.

I also saw in 1866, in Portland, a smaller dirt-bed, six feet below the principal one, six inches thick, consisting of brown earth with upright *Cycads* of the same species (*Mantellia nidiformis*, fig. 309) as those found in the upper bed, but no *Coniferæ*. The weight of the incumbent strata squeezing down the compressible dirt-bed, has caused the *Cycads* to assume that form which has led the quarrymen to call them 'petrified birds' nests,' which suggested to Brongniart the specific name of *nidiformis*. I am indebted to Mr. Carruthers for the annexed figure of one of these Purbeck specimens, in which the original cylindrical figure has been less distorted than usual by pressure; and I add a figure of the living Cycas that the student may have an idea of a form so predominant in Mesozoic vegetation.

The dirt-bed is by no means confined to the island of Portland, where it has been most carefully studied, but is seen in

the same relative position in the cliffs east of Lulworth Cove, in Dorsetshire, where, as the strata have been disturbed, and are

Fig. 309.

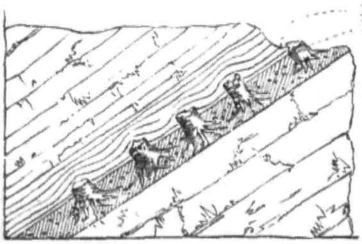
Mantellia nidiformis, Brongn.
The upper part shows the woody stem; the lower part the bases of the leaves.

Fig. 310.

Cycas circinalis. Living in the East Indies.[4]

now inclined at an angle of 45°, the stumps of the trees are also inclined at the same angle in an opposite direction—a beautiful

Fig. 311.



Section of cliff east of Lulworth Cove. (Buckland and De la Beche.)

illustration of a change in the position of beds originally horizontal (see fig. 311).

From the facts above described we may infer, first, that those beds of the Upper Oolite, called 'the Portland,' which are full of marine shells, were overspread with fluviatile mud, which

[4] Hooker, Descriptive and Analytical Botany, 1873, p. 752.

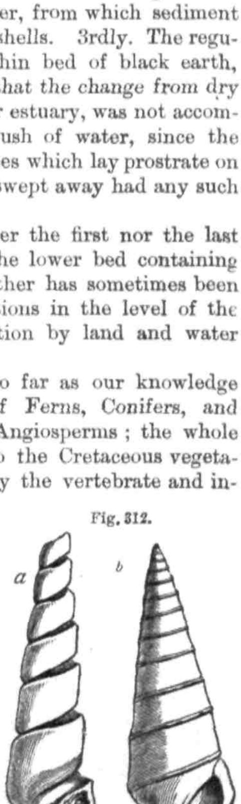
became dry land, and covered by a forest, throughout a portion of the space now occupied by the South of England, the climate being such as to permit the growth of the *Zamia* and *Cycas*. 2ndly. This land at length sank down and was submerged with its forests, beneath a body of fresh water, from which sediment was thrown down enveloping fluviatile shells. 3rdly. The regular and uniform preservation of this thin bed of black earth, over a distance of many miles, shows that the change from dry land to the state of a freshwater lake or estuary, was not accompanied by any violent denudation, or rush of water, since the loose black earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away had any such violent catastrophe taken place.

The forest of the dirt-bed was neither the first nor the last which grew in this region. Besides the lower bed containing upright *Cycadeæ*, just mentioned, another has sometimes been found above it, which implies oscillations in the level of the same ground, and its alternate occupation by land and water more than once.

The plants of the Purbeck beds, so far as our knowledge extends at present, consist chiefly of Ferns, Conifers, and Cycads, without any Dicotyledonous Angiosperms; the whole being more allied to the Oolitic than to the Cretaceous vegetation. The same affinity is indicated by the vertebrate and invertebrate animals. Mr. Brodie has found the remains of insects of the Coleopterous, Dipterous, Orthopterous, Hemipterous, and Neuropterous orders, and these orders have modern species, some of which now live on plants, while others hover over the surface of rivers.

Remains of Chelonia—genus, *Platemys*, of a Crocodile—*Goniopholis*, and Ganoid fish have been found in the strata. Finally, it is to be noticed that the Purbeck strata are very thick in Westphalia, where marine and freshwater conditions prevailed.

Fig. 312.

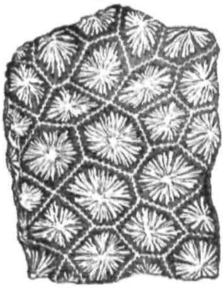


Cerithium Portlandicum (= *Terebra*), Sow., ⅔.
a. Cast of shell known as 'Portland screw.'
b. The shell itself.

Portland Oolite and Sand.—The Portland Oolite has already been mentioned as forming, in Dorsetshire, the foundation on which the freshwater limestone of the Lower Purbeck reposes (see p. 290). An interval of time, and some change in the physical geography

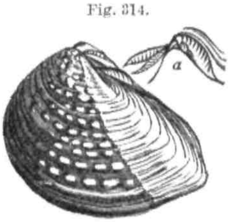
of the area occurred after the deposition of the Portland stone, for it was upheaved and worn and depressed, before the Purbecks were deposited upon it. The well-known building-stone of which St. Paul's and so many of the principal edifices of London are constructed, is Portland free-stone. About fifty species of mollusca occur in this formation, among which are some Ammonites of large size, such as *Ammonites giganteus. A. biplex* also occurs. The cast of a spiral univalve called by the quarrymen the 'Portland Screw' (*a*, fig. 312), is common;

Fig. 313.



Isastræa oblonga, M. Edw. and J. Haime, mag. 2 diams. Converted into chert from the Portland Sand, Tisbury.

Fig. 314.



Trigonia gibbosa. ½ nat. size. *a.* The hinge. Portland Stone, Tisbury.

the shell of the same (*b*) being rarely met with. Also *Trigonia gibbosa* (fig. 314) and *Cardium dissimile* (fig. 315). This upper member rests on a dense bed of sand, called the Portland sand, containing similar marine fossils, such as *Ostrea expansa* (fig. 316),

Fig. 315.

Cardium dissimile. ¼ nat. size. Portland Stone.

Fig. 316.

Ostrea expansa. Portland Sand.

below which is the Kimmeridge clay. In England these Upper Oolite formations are almost wholly confined to the southern counties. But some fragments of them occur beneath the Neocomian or Speeton clay on the coast of Yorkshire, containing many more fossils common to the Portlandian of the Continent than does the same formation in Dorsetshire. Corals are rare

in this formation, although one species is found plentifully at Tisbury, Wiltshire, in the Portland sand, converted into flint and chert, the original calcareous matter being replaced by silica (fig. 313).

The Crocodilia are *Steneosaurus* and *Goniopholis*, and *Cetiosaurus* is one of the Dinosauria.

Kimmeridge Clay.—The *Kimmeridge clay* consists, in great part, of a bituminous shale, sometimes forming an impure coal, several hundred feet in thickness. In some places in Wiltshire it much resembles peat; and the bituminous matter may have been, in part at least, derived from the decomposition of vegetables. But as impressions of plants are rare in these shales, which contain *Ammonites*, oysters, and other marine shells, with skeletons of fish and Reptilia, the bitumen may perhaps be of animal origin.

Among the fossils, amounting to nearly 100 species, may be mentioned *Cardium striatulum* (fig. 317) and *Ostrea deltoidea* (fig. 318), the latter found in the Kimmeridge clay throughout

Fig. 317.

Cardium striatulum, ⅔.
Kimmeridge Clay,
Hartwell.

Fig. 318.

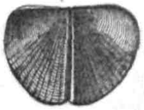
Ostrea deltoidea.
Kimmeridge Clay. ¼ nat. size.

Fig. 319.

Exogyra virgula, ⅔.
Kimmeridge Clay.

England and the North of France, and also in Scotland, near Brora. Many *Foraminifera* occur, and *Ammonites*. The *Exogyra virgula* (fig. 319), also met with in the Kimmeridge clay near Oxford, is so abundant in the Upper Oolite of parts of France, as to have caused the deposit to be termed 'marnes à gryphées virgules.' Near Clermont, in Argonne, a few leagues from St. Ménehould, where these indurated marls crop out from beneath the Gault, I have seen them, on decomposing, leave the surface of every ploughed field literally strewed over with this fossil oyster. The *Trigonellites latus* (*Aptychus* of some authors) (fig. 320) is also widely dispersed through this clay. It is probably the operculum of a cephalopod.

Fig. 320.



Trigonellites latus,
Park.
Kimmeridge Clay.

Solenhofen Stone.—The celebrated lithographic stone of Solenhofen, in Bavaria, appears to be of the age of the Kimmeridge clay. It affords a remarkable example of the variety of fossils which may be preserved under favourable circumstances, and what delicate impressions of the tender parts of certain animals and plants may be retained where the sediment is of extreme fineness. Although the number of testacea in this slate is small, and the plants few, and those all marine, Count Münster had determined no less than 237 species of fossils when I saw his collection in 1833; and among them no less than seven *species* of reptiles of the order Ornithosauria of Seeley, genus *Pterodactylus* (see fig. 321), six saurians, three tortoises, sixty species of fish, forty-six of crustacea, and twenty-six of insects. These insects, among which is a *Libellula*, or dragon-fly, must have been blown out to sea, probably from the same land to which the *Pterodactyli* and other contemporaneous air breathers resorted. Since that time the entire skeleton of a *Rhamphorynchus* has been found. It was a long-tailed, beaked, flying lizard, with teeth only in the hinder parts of the jaws.

Fig. 321.

Skeleton of *Pterodactylus crassirostris*.
Oolite of Pappenheim, near Solenhofen.
The bone *a*, consisting of four joints, is part of the fifth or outermost digit elongated, for the support of a wing.

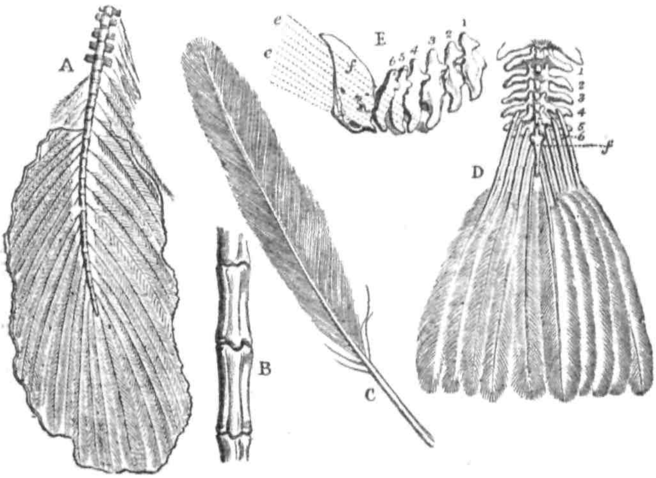
In the same slate of Solenhofen a fine example was met with in 1862 of the skeleton of a bird with teeth, almost entire, and retaining even its feathers so perfect, that the vanes as well as the shaft are preserved. It has been called by Professor Owen *Archæopteryx macrura*. Although anatomists agree that it is a true bird, yet they also find that in the length of the bones of the tail, and some other minor points of its anatomy, it approaches more nearly to reptiles than any known living bird. In the living representatives of the class Aves, the tail feathers are attached to a coccygian bone, consisting of several vertebræ united together; whereas in the *Archæopteryx* the tail is composed of twenty vertebræ, each of which supports a pair of quill feathers.

Professor Huxley, in his late memoir on the order of reptiles called Dinosaurians, which are largely represented in all the formations, from the Cretaceous to the Trias inclusive, has shown that they present in their structure many remarkable affinities to birds. But a reptile about two feet long, called

Compsognathus, found in the Stonesfield slate, makes a much greater approximation to the class Aves than any Dinosaur, and therefore forms a closer link between the classes Aves and Reptilia than does the *Archæopteryx*.

It appears doubtful whether any species of British fossil, whether of the vertebrate or invertebrate class, is common to the Oolite and Chalk. But there is no similar break or discordance

Fig. 322.



Tail and feather of *Archæopteryx*, from Solenhofen, and tail of living bird for comparison.

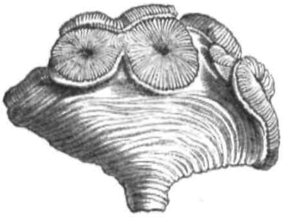
A. Caudal vertebræ of *Archæopteryx macrura*, Owen; with impression of tail feathers, ½ nat. size.
B. Two caudal vertebræ of same, nat. size.
C. Single feather, found in 1861 at Solenhofen, by Von Meyer, and called *Archæopteryx lithographica*. Nat. size.
D. Tail of recent vulture (*Gyps Bengalensis*), showing attachment of tail-feathers in living birds. ¼ nat. size.
E. Profile of caudal vertebræ of same, ⅓ nat. size. *e*, *e*. Direction of tail-feathers when seen in profile. *f*. Ploughshare bone or broad terminal joint (seen also in *f*, D).

as we proceed downwards, and pass from one to another of the several leading members of the Jurassic group, there being often a considerable proportion of the mollusca, sometimes as much as a fourth, common to such divisions as the Upper and Middle Oolite.

MIDDLE OOLITE.

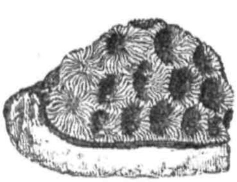
Coral Rag.—One of the limestones of the Middle Oolite has been called the 'Coral Rag,' because it consists, in part, of beds of fossil corals, some of them retaining the position in which they grew at the bottom of the sea. In their forms they frequently resemble the reef-building polyparia of the

Fig. 323.



Thecosmilia annularis, Milne Edw., ½; and J. Haime. Coral Rag, Steeple Ashton.

Fig. 324.



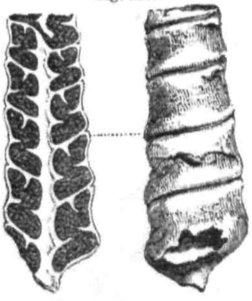
Thamnastræa, Coral Rag, Steeple Ashton.

Pacific. The number of species is small. They belong chiefly to the genera *Thecosmilia* (fig. 323), *Protoseris*, and *Thamnastræa* (fig. 324), and sometimes form masses of coral fifteen feet thick.

Fig. 325.

Ostrea gregarea, ⅓. Coral Rag, Steeple Ashton.

Fig. 326.



Nerinæa Goodhallii. Coral Rag, Weymouth. ¼ nat. size.

Mr. R. Tomes, F.G.S., has also discovered species of *Astrocœnia*, *Dimorpharæa*, *Latimæandraræa*, and *Crateroseris*. Echinodermata are numerous, and *Cidaris florigemma*, and species of *Pygurus*, *Pygaster*, and *Hemicidaris* are frequent. These coraline strata extend through the calcareous hills of the north-

west of Berkshire and north of Wilts, and again recur in Yorkshire, near Scarborough. The *Ostrea gregarea* (fig. 325) is very characteristic of the formation in England and on the Continent.

One of the limestones of the Jura, referred to the age of the English coral rag, has been called 'Nerinæan limestone' (Calcaire à Nérinées); *Nerinæa* being an extinct genus of univalve shells (fig. 326), much resembling *Cerithium* in external form. The annexed section shows the curious and continuous ridges on the columella and whorls.

Fig. 327.

Belemnites hastatus, ⅓.
Oxford Clay.

Fig. 328.

Belemnites Puzosianus, d'Orb.

B. Owenii, Pierce, ⅙.

Oxford Clay, Christian Malford.

a. Section of the shell projecting from the phragmacone.
b–c. External covering to the ink-bag and phragmacone.
c, d. Osselet, or guard, or that portion commonly called the belemnite.
e. Conical chambered body called the phragmacone.
f. Position of ink-bag beneath the shelly covering.

Fig. 329.

Ammonites Jason, Reincke. (Syn. *A. Elizabethæ*, Pratt.)
Oxford Clay, Christian Malford, Wiltshire.

Oxford Clay.—The coralline limestone, or 'coral rag,' above described, and the accompanying sandy beds, called 'Calcareous grits,' of the Middle Oolite, rest on a thick bed of clay, called the 'Oxford clay,' sometimes not less than 600 feet thick. In this there are no corals, but great abundance of Cephalopoda, of

the genera *Ammonites* and *Belemnites*. In some of the finely laminated clays, *Ammonites* are very perfect, although somewhat compressed, and they are frequently found with the lateral lobe extended on each side of the aperture into a horn-like projection. (See fig. 329.)

Similar elongated processes have been also observed to extend from the phragmacone of some belemnites discovered by Dr. Mantell in the same clay (see fig. 328), who, by the aid of this and other specimens, has been able to throw much light on the structure of singular extinct forms of Cuttle fish.[5]

Remains of the Reptilian genera, *Ichthyosaurus*, *Pliosaurus*, *Plesiosaurus*, *Megalosaurus*, and *Rhamphorynchus* are found.

Kelloway Rock.—The arenaceous limestone which passes under this name, is generally grouped as a member of the Oxford clay, in which it forms, in the south-west of England, lenticular masses, 8 or 10 feet thick, containing, at Kelloway, in Wiltshire, numerous casts of *Ammonites*, and other shells. But in Yorkshire this calcareo-arenaceous formation thickens to about 30 feet, and constitutes the lower part of the Middle Oolite, extending inland from Scarborough in a southerly direction. The number of mollusca which it contains is, according to Mr. Etheridge, 143, of which only 34, or 23½ per cent., are common to the Oxford clay proper. Of the 52 Cephalopoda, 15 (namely, 13 species of *Ammonites*, the *Ancyloceras Calloviense* and one *Belemnite*) are common to the Oxford clay, giving a proportion of nearly 30 per cent.

LOWER OOLITE.

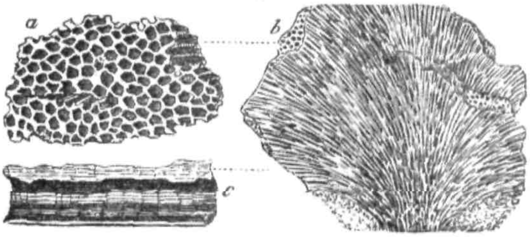
Cornbrash and Forest Marble.—The upper division of this series, which is more extensive than the preceding or Middle Oolite, is called in England the Cornbrash, as being a brashy, easily broken rock, good for corn land. It consists of clays and calcareous sandstones, which pass downwards into the Forest-marble, an argillaceous limestone, abounding in marine fossils. The Echinoidea, *Echinobrissus clunicolaris*, *E. orbicularis*, and *Holectypus depressus*, and also the bivalve *Avicula echinata*, are common. In some places, as at Bradford, near Bath, this limestone is replaced by a mass of clay (see p. 301). The sandstones of the Forest-marble of Wiltshire are often ripple marked and filled with fragments of broken shells and pieces of driftwood, having evidently been formed on a coast. Rippled slabs of fissile oolite are used for roofing, and have been traced over a

[5] See Phil. Trans. 1850, p. 363; also Huxley, Memoirs of Geol. Survey, 1864; Phillips, Paleont. Soc.

broad band of country from Bradford in Wilts, to Tetbury in Gloucestershire. These calcareous tile-stones are separated from each other by thin seams of clay, which have been deposited upon them, and have taken their form, preserving the undulating ridges and furrows of the sand in such complete integrity, that the impressions of small footsteps, apparently of Crustacea, which walked over the soft, wet sands, are still visible. In the same stone the claws of crabs, fragments of Echini, and other signs of a neighbouring beach, are still observed.[6]

Great (or Bath) Oolite.—Although the name of coral rag has been appropriated, as we have seen, to the highest member of the Middle Oolite before described, some portions of the Lower Oolite are equally entitled in many places to be called coralline limestones. Thus the Great Oolite near Bath contains

Fig. 330.



Calamophyllia radiata, Lamouroux.

a. Section transverse to the tubes.
b. Vertical section, showing the radiation of the tubes.
c. Portion of interior of tubes magnified, showing striated surface.

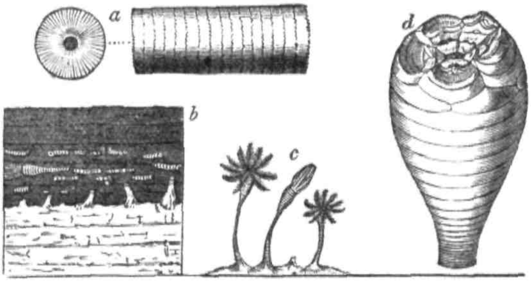
various corals, among which *Calamophyllia radiata* (fig. 330) is very conspicuous, single individuals forming masses several feet in diameter; and having probably occupied much time in growing, like the large existing Brain coral (*Meandrina*) of the tropics.

Different species of Crinoids, or stone-lilies, are also common in the same rocks with corals; and, like them, must have lived on a firm bottom, where their base of attachment remained undisturbed for years (*c*, fig. 331). Such fossils, therefore, are almost confined to the limestones; but an exception occurs at Bradford, near Bath, in the Forest-marble series, where they are enveloped in clay sometimes 60 feet thick. In this case, however, it appears that the solid upper surface of the 'Great Oolite' had supported, for a time, a thick submarine forest of these beautiful crinoids, until the clear and still water

6 P. Scrope. Proc. Geol. Soc. March 1831.

was invaded by a current charged with mud, which threw down the Stone-lilies, and broke most of their stems short off near the point of attachment. The stumps still remain in their original position; but the numerous articulations, once composing the stem, arms, and body of the Encrinite, were scattered at random through the argillaceous deposit, in which some now lie prostrate. These appearances are represented in

Fig. 331.



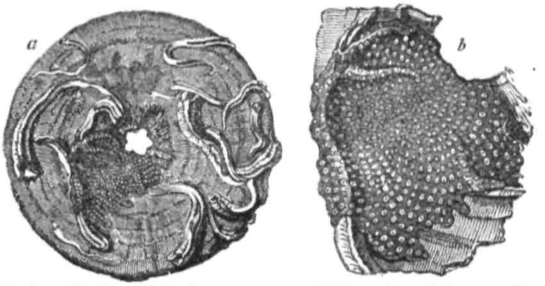
Apiocrinites rotundus, or Pear Encrinite; Miller. Fossil at Bradford, Wilts.

a. Stem of *Apiocrinites*, and one of the articulations, natural size.
b. Section at Bradford of Great Oolite and overlying clay, containing the fossil encrinites.
c. Three perfect individuals of *Apiocrinites*, represented as they grew on the surface of the Great Oolite.
d. Body of the *Apiocrinites rotundus*. Half nat. size.

the section b, fig. 331, where the darker strata represent the Bradford clay, which is, however, a formation of such local development that in many places it cannot be easily separated from the clays of the overlying 'Forest-marble' and underlying 'Fuller's earth.' The upper surface of the calcareous stone below is completely incrusted over with a continuous pavement, formed by the stony roots or attachments of the Crinoidea; and, besides this evidence of the length of time they had lived on the spot, we find great numbers of single joints, of the stem and body of the encrinite, covered over with *Serpulæ*. Now these *Serpulæ* could only have begun to grow after the death of some of the Stone-lilies, parts of whose skeletons had been strewed over the floor of the ocean before the irruption of argillaceous mud. In some instances we find that, after the parasitic *Serpulæ* were full grown, they had become incrusted over with a bryozoan, called *Diastopora diluviana* (see b, fig. 332), and many generations of these molluscoids had succeeded each other in the pure water, before they became fossil.

We may, therefore, perceive distinctly, that, as the Pines and Cycads, the plants of the ancient 'dirt-bed,' or fossil forest, of the Lower Purbeck were killed by submergence under fresh water, and soon buried beneath muddy sediment, so an invasion

Fig. 332.



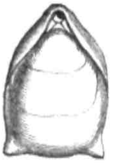
a. Single plate of body of *Apiocrinus*, overgrown with *Serpulæ* and *Bryozoa*. Natural size. Bradford Clay.
b. Portion of the same magnified, showing the bryozoan *Diastopora diluviana* covering one of the *Serpulæ*.

of argillaceous matter put a sudden stop to the growth of the Bradford Encrinites, and led to their preservation in marine strata.

The calcareous portion of the great Oolite, consists of several shelly limestones, one of which, called the Bath Oolite, is much celebrated as a building-stone. In parts of Gloucestershire, especially near Minchinhampton, the Great Oolite, says Mr. Lycett, 'must have been deposited in a shallow sea, where strong currents prevailed, for there are frequent changes in the mineral character of the deposit, and some beds exhibit false stratification. In others, heaps of broken shells are mingled with pebbles of rocks foreign to the neighbourhood, and with fragments of abraded corals, dicotyledonous wood, and crabs' claws. The shelly strata, also, have occasionally suffered denudation, and the removed portions have been replaced by clay.' In such shallow-water beds, shells of the genera *Patella*, *Nerita*, *Rimula*, and *Cylindrites* are common (see figs. 335 to 338); while cephalopods are rare, and, instead of *Ammonites* and *Belemnites*, numerous genera of carnivorous trachelipods appear. Out of 224 species of univalves obtained from the Minchinhampton beds, Mr. Lycett found no less than 50 to be carnivorous. They belong principally to the genera *Buccinum*, *Pleurotoma*, *Rostellaria*, *Murex*, *Purpuroidea* (fig. 334), and *Fusus*, and exhibit a proportion of zoophagous species not very different from that which occurs in seas of the Recent period. These zoological

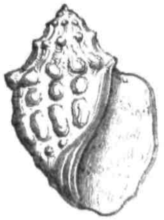
results are curious and unexpected, since it was imagined that we might look in vain for the carnivorous trachelipods in rocks of such high antiquity as the Great Oolite, and it was a

Fig. 333.



Terebratula digona, Sow., nat. size. Bradford Clay.

Fig. 334.



Purpuroidea nodulata, ¼ nat. size. Great Oolite, Minchinhampton.

Fig. 335.

Cylindrites acutus, Sow. Syn. *Actæon acutus*, nat. size. Great Oolite, Minchinhampton.

received doctrine that they did not begin to appear in considerable numbers till the Eocene period, when those two great families of Cephalopoda, the *Ammonites* and *Belemnites*, had become extinct.

Stonesfield Slate: Mammalia.—The slate of Stonesfield has been shown by Mr. Lonsdale to lie at the base of the Great

Fig. 336.

Patella rugosa, Sow., ⅔. Great Oolite.

Fig. 337.

Nerita costulata, Desh., mag. 2 diams. Great Oolite.

Fig. 338.

Rimula (*Emarginula*) *clathrata*, Sow., mag. 3 diams. Great Oolite.

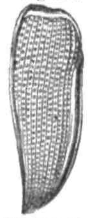
Oolite.[7] It is a slightly oolitic shelly limestone, forming large lenticular masses embedded in sand, only 6 feet thick, but very rich in organic remains. It contains some pebbles of a rock very similar to itself, and which may be portions of the deposit, broken up on a shore at low water or during storms, and redeposited. The remains of *Belemnites*, *Trigoniæ*, and other marine remains, with fragments of wood, are common, and impressions of ferns, Cycadeæ, and Conifers. Several insects, also, and, among the rest, the elytra or wing-covers of beetles, are perfectly preserved (see fig. 339), some of them approaching nearly to the genus *Buprestis*. The remains, also, of many

[7] Proceedings Geol. Soc. vol. i. p. 414.

genera of reptiles, such as *Ichthyosaurus*, *Pliosaurus*, *Plesiosaurus*, *Cetiosaurus*, *Teleosaurus*, *Megalosaurus*, and *Rhamphorynchus*, have been discovered in the same limestone.

There have also been discovered no less than ten specimens of lower jaws of marsupial mammiferous quadrupeds, belonging to

Fig 339.



Elytron of *Buprestis?* nat. size. Stonesfield.

Fig. 340.

Tupaia Tana.

Right ramus of lower jaw. Natural size.
A recent insectivorous placental mammal, from Sumatra.

four different genera, for which the names of *Amphitherium*, *Amphilestes*, *Phascolotherium*, and *Stereognathus* have been adopted.

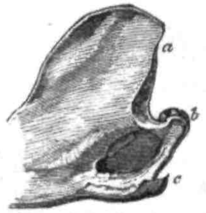
It is now generally admitted that these are really the remains of mammalia (although it was at first suggested that they might be reptiles), and the only question open to controversy is limited

Fig. 341.

Fig. 342.

Fig. 343.

Fig. 344.



Part of lower jaw of *Tupaia Tana*. Twice natural size.
Fig. 341. End view seen from behind, showing the very slight inflection of the angle at *c*.
Fig. 342. Side view of same.

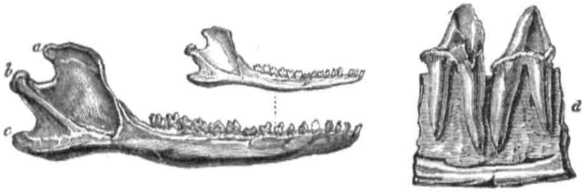
Part of lower jaw of *Didelphys Azaræ*; recent, Brazil. Natural size.
Fig. 343. End view seen from behind, showing the inflection of the angle of the jaw, *c*, *d*.
Fig. 344. Side view of same.

to this point, whether the fossil mammalia found in the Lower Oolite of Oxfordshire ought to be referred to the marsupial quadrupeds, or to the ordinary placental series. Cuvier had long ago pointed out a peculiarity in the form of the angular process (*c*, figs. 343 and 344) of the lower jaw, as a character of

the genus *Didelphys*; and Professor Owen has since confirmed the doctrine of its generality in the entire marsupial series. In all these pouched quadrupeds this process is turned inwards, as at *c*, *d*, fig. 343, in the Brazilian opossum, whereas in the placental series, as at *c*, figs. 341 and 342, there is an almost entire absence of such inflection. The *Tupaia Tana* of Sumatra has been selected by Mr. Waterhouse for this illustration, because the jaws of that small insectivorous quadruped bear a great resemblance to those of the Stonesfield *Amphitherium*. By clearing away the matrix from the specimen of *Amphitherium*

Fig. 345.

Natural size.



Amphitherium Prevostii, Cuv. sp. Stonesfield Slate.
Syn. *Thylacotherium Prevostii*, Valenc.

a. Coronoid process. *b*. Condyle. *c*. Angle of jaw. *d*. Double-fanged molars.

Prevostii here represented (fig. 345), Professor Owen ascertained that the angular process (*c*) bent inwards in a slighter degree than in any of the known marsupialia; in short, the inflection does not exceed that of the mole or hedgehog. This fact made him doubt whether the *Amphitherium* might not be an insectivorous placental, although it offered some points of approximation in its osteology to the marsupials, especially to the *Myrmecobius*, a small insectivorous quadruped of Australia which has nine molars on each side of the lower jaw, besides a canine and three incisors.[8] Another species of *Amphitherium* has been found at Stonesfield (fig. 346), which differs from the former (fig. 345) principally in being larger.

The second mammiferous genus discovered in the same slates was named originally by Mr. Broderip *Didelphys Bucklandi* (see fig. 347), and has since been called *Phascolotherium* by Owen. It manifests a much stronger likeness to the marsupials in the general form of the jaw, and in the extent and position of its inflected angle, while the agreement with the living genus

[8] A figure of this recent *Myrmecobius* will be found in my Principles of Geology, chap. ix.

Didelphys in the number of the pre-molar and molar teeth is complete.[9]

In 1854 the remains of another mammifer, small in size, but larger than any of those previously known, was brought to light. The generic name of *Stereognathus* was given to it, and as is usually the case in these old rocks, it consisted of part of

Fig. 346.

Amphitherium Broderipii, Owen. Natural size. Stonesfield Slate.

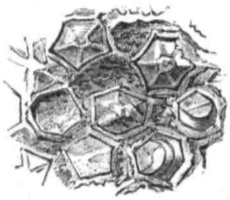
Fig. 347.

Phascolotherium Bucklandi, Broderip sp. *a*. Natural size. *b*. Molar of same, magnified.

a lower jaw, in which were implanted three double-fanged teeth, differing in structure from those of all other known recent or extinct mammals.

Plants of the Slate.—At least twelve genera of ferns are found, *Pecopteris*, *Sphenopteris*, and *Tæniopteris* being common; and *Palæozamia*, a Cycad, and the Conifer *Thuyites*. The

Fig. 348.



Portion of a fossil fruit of *Podocarya Bucklandi*, Ung., magnified. (Buckland's Bridgw. Treatise. Pl. 63.) Inferior Oolite, Charmouth, Dorset.

Fig. 349.

Cone of fossil *Araucaria Sphærocarpa*, Carr. Inferior Oolite. Bruton, Somersetshire. ½ diameter of original. In the collection of the British Museum.

Araucarian pines, which are now abundant in Australia and its islands, together with marsupial quadrupeds, are found in like manner to have accompanied the marsupials in Europe during the Oolitic period. In the same rock, endogens of the most perfect structure are met with, as, for example, fruits allied to the

[9] Owen's British Fossil Mammals, p. 62.

Pandanus, such as the *Kaidacarpum ooliticum* of Carruthers in the Great Oolite and the *Podocarya* of Buckland (see fig. 349) in the Inferior Oolite.

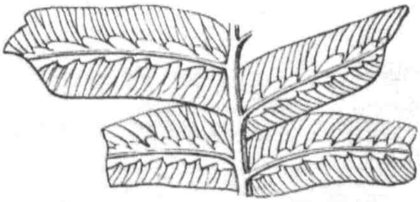
Fig. 350.

Ostrea acuminata, Fuller's Earth.

Fuller's Earth.—Between the Great and Inferior Oolite in the West of England, an argillaceous deposit, called 'the Fuller's earth,' occurs; but it is wanting in the North of England. It abounds in the small oyster represented in fig. 350. The number of mollusca known in this deposit is about seventy; namely, fifty Lamellibranchiate Bivalves, ten Brachiopods, three Gasteropods, and seven or eight Cephalopods; most are common to the Great Oolite.

Inferior Oolite.—This formation consists of a calcareous freestone and shelly limestones, usually of small depth, but attaining in some places, near Cheltenham, a thickness of 269 feet. It rests conformably on the Lias, and many species (40) pass from this lower to the upper formation. It sometimes rests upon yellow sands, formerly classed as the sands of the Inferior Oolite, but now regarded as a member of the Upper Lias. These Midford sands repose upon the Upper Lias clays in the South and West of England. The Collyweston slate, formerly classed with the Great Oolite, and supposed to represent the Northamptonshire and Stonesfield slate, is now found to belong to the Inferior Oolite, both by community of species and position in the series. The Collyweston beds, on the whole, assume a much more marine character than the Stonesfield slate. Nevertheless,

Fig. 351.



Hemitelites Brownii, Goepp. Syn. *Phlebopteris contigua*, Lind. and Hutt. Lower carbonaceous strata, Inferior Oolite shales. Gristhorpe, Yorkshire.

one of the fossil plants (*Aroides Stutterdi*, Carr.), remarkable, like the Pandanaceous species before mentioned (fig 348), as a representative of the monocotyledonous class, is also common to the Stonesfield beds in Oxfordshire.

The Inferior Oolite of Yorkshire (800 feet) consists largely of shelly limestones, shales, ironstones, and sandstones, which

assume much the aspect of a true coal-field, thin seams of coal having actually been worked in them for more than a century. A rich harvest of fossil ferns has been obtained from them at Gristhorpe, near Scarborough (fig. 351). The strata contain many Cycadeæ, of which family a magnificent specimen has been described by Prof. Williamson under the name *Zamia gigas*, and a fossil called *Equisetum columnare* (see fig. 400), which maintains an upright position in sandstone strata over a wide area. Shells of *Estheria* and *Unio*, collected by Mr. Bean from these Yorkshire coal-bearing beds, point to the estuarine or fluviatile origin of the deposit.

At Brora, in Sutherlandshire, a coal-seam probably coeval with the above,[1] or at least older than the Kelloway Rock, the

Fig. 352.

Terebratula fimbria, Sow., ½. Inferior Oolite marl. Cotswold Hills.

Fig. 353.

Rhynchonella spinosa, Schloth, ⅔. Inferior Oolite.

Fig. 354.

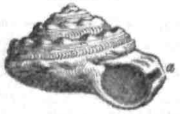
Pholadomya fidicula, Sow., ⅓ natural size. Inferior Oolite.

lowest marine bed of the Middle Oolitic period, was extensively mined nearly a century ago. It affords the thickest stratum of pure vegetable matter hitherto detected in any secondary rock

Fig. 355.

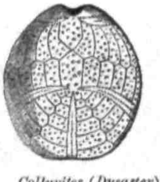
Pleurotomaria granulata, Sow., ½. Ferruginous Ool., Normandy. Inferior Oolite, England. Under side.

Fig. 356.



Pleurotomaria ornata, Sow. sp. Inferior Oolite. ½ nat. size.

Fig. 357.



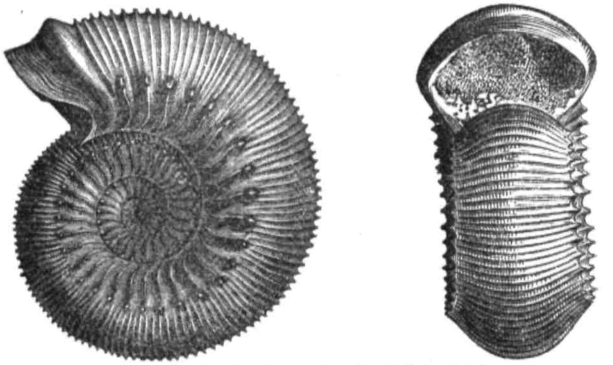
Collyrites (Dysaster) ringens, Agass. Inf. Ool., Somersetshire.

in England, upwards of 80,000 tons having been extracted. One seam of coal of good quality, 3½ feet thick, is now being worked, and there is pyritous coal resting upon it. The roof-bed of the coal is literally composed of marine shells, such as *Pholadomya*, *Trigonia*, *Goniomya*, *Pteroperna*, *Cerithium*, &c.

1 See Judd, Quart. Journ. Geol. Soc. vol. xxix. p. 164.

Among the characteristic shells of the Inferior Oolite, I may instance *Terebratula fimbria* (fig. 352), *Rhynchonella spinosa* (fig. 353), and these two genera predominate over other Brachiopoda. *Pholadomya fidicula* (fig. 354) is found. The genus *Pleurotomaria* is also a form very common in this division as well as in the Oolitic system generally. It resembles *Trochus*

Fig. 358.



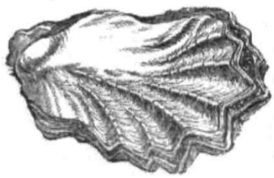
Ammonites Humphresianus, Sow., ½. Inferior Oolite.

in form, but is marked by a deep cleft (*a*, figs. 355, 356) on one side of the aperture. The *Collyrites* (*Dysaster*) *ringens* (fig. 357) is an Echinoderm common to the Inferior Oolite of England and France, as are the two *Ammonites* (figs. 358, 359). The

Fig. 359.

Ammonites Braikenridgii, Sow., ½.
Oolite, Scarborough.
Inf. Ool., Dundry; Calvados, &c.

Fig. 360.



Ostrea Marshii. ½ natural size.
Middle and Lower Oolite.

important *Ammonites* are *A. Parkinsoni*, *A. Humphresianus*, *A. Sowerbyi*, and *A. Murchisoniæ*.

Palæontological relations of the Oolitic strata.—Observations have already been made (p. 297) on the distinctness of the organic remains of the Oolitic and Cretaceous strata, and the proportion of species common to the different members of

the Oolite. Between the Lower Oolite and the Lias there is a somewhat greater break, for out of 256 mollusca of the Upper Lias, thirty-seven species only pass up into the Inferior Oolite. Corals are frequent, but have a very restricted distribution, and do not pass up from one set of strata to others.

In illustration of shells having a great vertical range, it may be stated that in England some few species pass up from the Lower to the Upper Oolite, as, for example, *Rhynchonella obsoleta*, *Lithodomus inclusus*, *Pholadomya ovalis*, and *Trigonia costata*.

Fig. 361.

Ammonites macrocephalus, Schloth. ½ nat. size. Great Oolite and Oxford Clay.

Of all the Jurassic Ammonites of Great Britain, *A. macrocephalus* (fig. 361), which is common to the Great Oolite and Oxford clay, has the widest range.

We have every reason to conclude that the gaps which occur, both between the larger and smaller sections of the English Oolites, imply intervals of time elsewhere represented by fossiliferous strata, although no deposit may have taken place in the British area. This conclusion is warranted by the partial extent of many of the minor and some of the larger divisions even in England.

In North-Western Germany there is a very similar succession of Oolitic rocks to those just described. The Malm, or white Jura corresponds to the Upper and part of the Middle Oolite, and it consists of white limestones and marls. The Dogger, or Brown Jura, has dark-coloured clays and ironstones, but the limestones are rare: it corresponds to the Lower Oolite. In France, the Oolitic deposits are grandly developed, and vary from the English types as they are traced to the south and east. The Jura mountains contain part of the formation, and it is also found in Italy.

Oolitic rocks are doubtfully represented in America, but they are fully developed in Cutch and in the Himalayas. Important traces of them exist in Australia and New Zealand.

CHAPTER XXI.

JURASSIC GROUP—*continued.* LIAS.

Mineral character of Lias—Numerous successive zones in the Lias marked by distinct fossils, without unconformity in the stratification, or change in the mineral character of the deposits—Gryphite limestone—Shells of the Lias—Fish of the Lias—Reptiles of the Lias—Ichthyosaurus and Plesiosaurus—Marine Reptile of the Galapagos Islands—Sudden destruction and burial of fossil animals in Lias—Fluvio-marine beds in Gloucestershire, and insect limestone—Fossil plants—Origin of the Oolite and Lias, and of alternating calcareous and argillaceous formations.

Lias.—The English provincial name of Lias has been very generally adopted for three formations of argillaceous limestone, marl, and clay, which lie below the Oolites. The peculiar aspect which is most characteristic of the Lias in England, France, and Germany, is an alternation of thin beds of blue or grey limestone, having a surface which becomes light-brown when weathered, these beds being separated by dark-coloured narrow argillaceous partings, so that the quarries of this rock, seen at a distance, assume a striped and riband-like appearance.

The Lias has been divided, in England, into three groups, the Upper, Middle, and Lower. The Upper Lias consists in places first of sands, which were formerly regarded as the base of the Oolite, but which, according to Dr. Wright, are by their fossils more properly referable to the Lias; secondly, of clay shale and thin beds of limestone. The Middle Lias, or marlstone series, has been divided into three zones, and contains in its upper beds the deposits of earthy carbonate of iron ore which are so extensively worked in the Cleveland district in Yorkshire. The Lower Lias, according to the labours of Quenstedt, Oppel, Strickland, Wright, and others, has been divided into seven zones, each marked by its own group of fossils. This Lower Lias averages from 600 to 900 feet in thickness. The deposits of the Lias as a whole, collected in shallow seas near coast-lines.

From Dorsetshire to Yorkshire all these divisions, observes Sir A. Ramsay, are constant; and from top to bottom we cannot assert that anywhere there is actual unconformity between any two subdivisions, whether of the larger or smaller kind.

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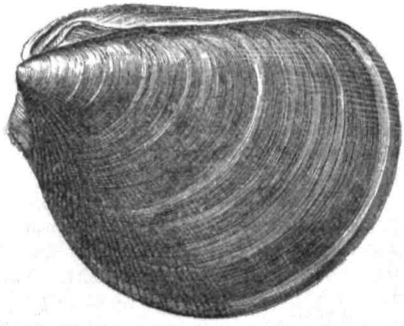
FOSSILS OF THE LIAS.

In the whole of the English Lias, there are at present known about 900 species of mollusca, and of these 293 are Cephalopoda, of which class more than 130 species are *Ammonites*. There are 9 species of *Nautilus*; and *Belemnites* also abound. The Lias has been divided by zones characterised by particular *Ammonites*; for while other families of shells pass from one division to another in numbers varying from about 20 to 50 per cent., these Cephalopods are almost always limited to single zones, as Quenstedt and Oppel have shown for Germany, and Dr. Wright and Professor Blake for England.

As no actual unconformity is known from the top of the Upper to the bottom of the Lower Lias, and a general uniformity in the mineral character of almost all the strata is apparent, it is somewhat difficult to account even for such partial breaks as have been alluded to in the succession of species, if we reject the hypothesis that the old species were in each case destroyed at the close of the deposition of certain rocks containing them, and replaced by the creation of new forms when the succeeding formation began. I agree with Sir A. Ramsay in not accepting this

Fig. 362.



Plagiostoma (*Lima*) *gigantea*, Sow., ½. Lias.

Fig. 363.

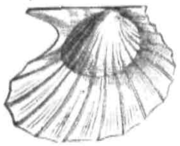
Gryphæa incurva, Sow., ½. (*G. arcuata*, Lam.) Lias.

hypothesis. No doubt some of the old species occasionally died out, and left no representatives in Europe or elsewhere; others were locally exterminated in the struggle for life by species which invaded their ancient domain, or by varieties better fitted for a new state of things. Pauses also of vast duration may have occurred in the deposition of strata, allowing time for

the modification of organic life throughout extensive areas, slowly brought about by variation accompanied by extinction of some of the original forms.

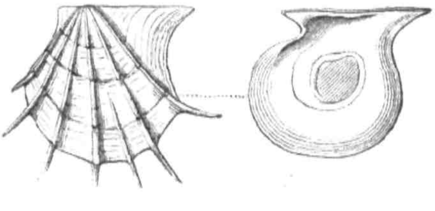
The name of Gryphite limestone has sometimes been applied

Fig. 364.



Avicula inæquivalvis, Sow., $\frac{8}{9}$. Lower Lias.

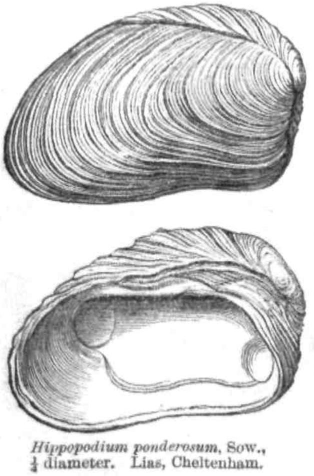
Fig. 365.



Avicula cygnipes, Phil., $\frac{1}{3}$. Lower Lias, Gloucestershire and Yorkshire.
a. Lower valve. *b*. Upper valve.

to the Lower Lias, in consequence of the great number of shells which it contains of a species of oyster, or *Gryphæa* (fig. 363). A large heavy shell called *Hippopodium* (fig. 366) is also charac-

Fig. 366.

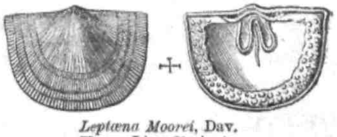


Hippopodium ponderosum, Sow., $\frac{1}{4}$ diameter. Lias, Cheltenham.

Fig. 367.

Spiriferina (*Spirifera*) *Walcotii*, Sow., $\frac{1}{2}$. Lower Lias.

Fig. 368.

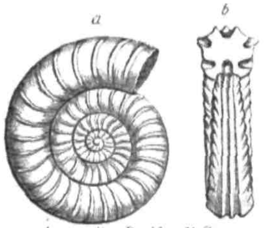


Leptæna Moorei, Dav. Upper Lias, Ilminster.

teristic of the upper part of the Lower Lias. In this formation occur also the *Aviculæ* (figs. 364 and 365). The Upper Lias formation is also remarkable for being the newest of the secondary

rocks in which the two genera of Brachiopoda, *Spiriferina* and *Leptæna* (figs. 367, 368), occur, although the former is slightly modified in structure so as to constitute the subgenus *Spiriferina* (Davidson), and the *Leptæna* has dwindled in size to a shell smaller than a pea. The Spiriferidæ came in during the

Fig. 369.



Ammonites Bucklandi, Sow.
" *bisulcatus*, Brug.
⅓ diameter of original.

a. Side view. *b*. Front view, showing mouth and bisulcated keel. Characteristic of the Lower Lias of England and the Continent.

Fig. 370.

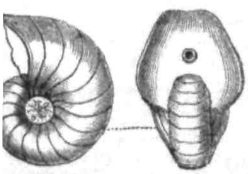
A. planorbis, Sow.,
½ diameter of original.

From the base of the Lower Lias of England and the Continent.

Upper Silurian age, dwindled in the Lias, and did not reach up higher than the Oolite.

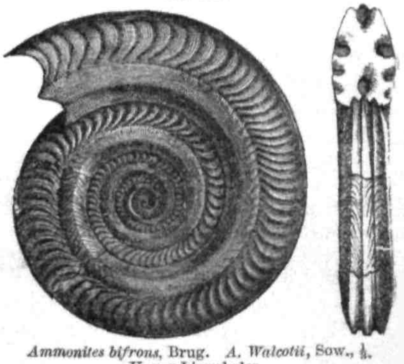
Allusion has already been made to numerous zones in the

Fig. 371.



Nautilus truncatus, Sow.
Lias. ⅓ nat. size.

Fig. 372.



Ammonites bifrons, Brug. *A. Walcotii*, Sow., ½.
Upper Lias shales.

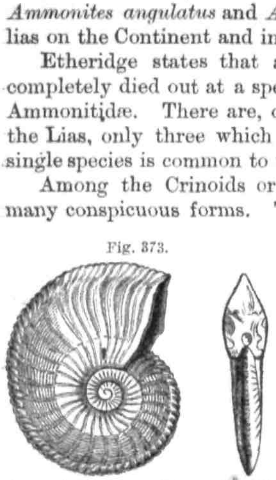
Lias having each their peculiar species of *Ammonites*. Two of these zones occur near the base of the Lower Lias, and have a thickness varying from 40 to 80 feet. The upper is characterised by *Ammonites Bucklandi*, and the lower by *Ammonites planorbis*

(see figs. 369, 370).[1] Sometimes, however, there is a third intermediate zone, that of *Ammonites angulatus*. The zones of *Ammonites angulatus* and *Ammonites planorbis* form the Infra-lias on the Continent and in the United Kingdom.

Etheridge states that as a group, probably no other so completely died out at a special geological age as did species of Ammonitidæ. There are, of the 293 species of *Ammonites* of the Lias, only three which are found in the Oolites, and not a single species is common to the three divisions of the formation.

Among the Crinoids or Stone-lilies of the Lias, there are many conspicuous forms. The *Extracrinus Briareus* (fig. 374) occurs in tangled masses, sometimes attached to fossil wood or forming thin beds of considerable extent, in the Lower Lias of Dorset, Gloucestershire, and Yorkshire. The remains are often highly charged with pyrites. This Crinoid, with its innumerable tentacular arms, appears to have been frequently attached to the driftwood of the Liassic sea, in the same manner as Barnacles float about on wood at the present day. There is another species of *Extracrinus* and several of *Pentacrinus* in the Lias; and the latter genus is found in nearly all the formations, from the Lias to the London clay inclusive. It is represented in the present seas by the delicate and rare *Pentacrinus caput-medusæ* of the Antilles, which, with the genus *Comatula*, is one of the few surviving members of the ancient family of the Crinoidea, represented by so many extinct genera in the older formations. In 1870 Mr. Gwyn Jeffreys dredged up a new living species of Pentacrinus from a depth of 6,570 feet off the coast of Portugal, to which he gave the name of *P. Wyville Thomsoni*,[2] and several other genera have been described by Mr. Herbert Carpenter from the dredgings of H.M.S. 'Challenger.'

Fig. 373.



Ammonites margaritatus, Montf. Syn. *A. Stokesii*, Sow. *A. Clevelandicus*, Y. and B. Middle Lias. ½.

Of *Palæocoma* (*Ophioderma*) *tenuibrachiata* (fig. 375), referable to the *Ophiuridæ* of Müller, perfect specimens have been met with in the Middle Lias beds of Dorset and Yorkshire.

Fishes of the Lias.—The fossil fish, of which there are no less than 132 species known as British, resemble generically those of the Oolite, but many differ, according to M. Agassiz,

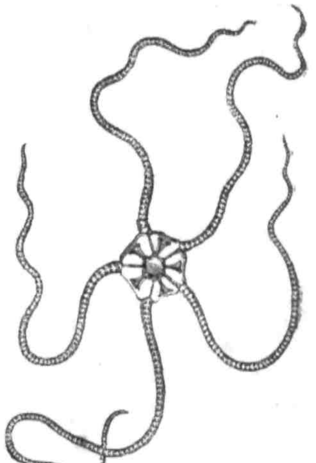
[1] Quart. Journ. Geol. Soc. vol. xvi. p. 376.
[2] Wyville Thomson, Depths of the Sea, p. 442.

from those of the Cretaceous period. Among them is a species of *Lepidotus* (*L. gigas*, Agass.), fig. 376, which is found in the

Fig. 374.

Extracrinus (Pentacrinus) Briareus. Miller, ½ natural size. (Body, arms, and part of stem.) Lower Lias, Lyme Regis.

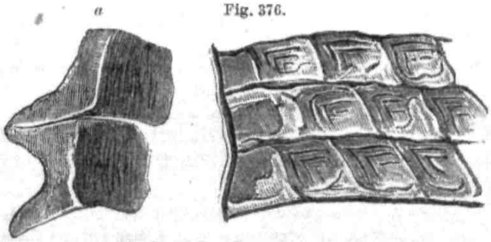
Fig. 375.



Palæocoma (Ophioderma) tenuibrachiata, E. Forbes. Middle Lias, Seatown, Dorset.

Lias of England, France, and Germany.[3] This genus was before mentioned as occurring in the Wealden, and is sup-

Fig. 376.



Scales of *Lepidotus gigas*, Agass.
a. Two of the scales detached.

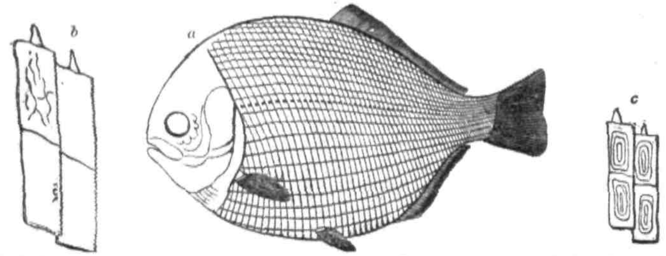
posed to have frequented both rivers and sea-coasts. Another genus of Ganoids (fish possessing hard, shining, and enamelled scales), called *Æchmodus* (fig. 377), is almost exclusively Liassic.

[3] Agassiz, Poissons Fossiles, vol. ii. tab. 28, 29.

The teeth of a species of *Acrodus*, also, are very abundant in the Lower Lias (fig. 378).

But the remains of fish which have excited more attention

Fig. 377.



b. Scales of *Æchmodus Leachii*. *a*. *Æchmodus*. Restored outline. *c*. Scales of *Dapediu monilifer*.

than any others are those large bony spines called *Ichthyodorulites* (*a*, fig. 379), once supposed by some naturalists to be jaws,

Fig. 378.

Acrodus nobilis, Agass. (tooth); commonly called 'fossil leech.' Lias, Lyme Regis and Germany, nat. size.

and by others weapons, resembling those of the living *Balistes* and *Silurus*; but which M. Agassiz has shown to be neither the

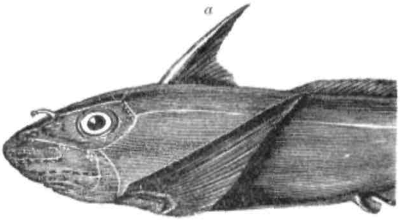
Fig. 379.

Hybodus reticulatus, Agass. Lias, Lyme Regis.
a. Part of fin, commonly called an Ichthyodorulite. *b*. Tooth.

one nor the other. The spines, in the genera last mentioned, articulate with the backbone, whereas there are no signs of any such articulation in the Ichthyodorulites. These last appear to

have been bony spines which formed the anterior part of the dorsal fin, like that of the living genera *Cestracion* and *Chimæra* (see *a*, fig. 380). In both of these genera, the posterior concave face is armed with small spines, as in that of the fossil *Hybodus* (fig. 379), a placoid fish of the shark family found fossil at Lyme Regis. Such spines are simply embedded in the flesh, and attached to strong muscles. 'They serve,' says Dr. Buckland,

Fig. 380.



Chimæra monstrosa.[4]
a. Spine forming anterior part of the dorsal fin.

as in the *Chimæra* (fig. 380), 'to raise and depress the fin, their action resembling that of a moveable mast, raising and lowering backwards the sail of a barge.'[5]

Reptiles of the Lias.—It is not, however, the fossil fish which form the most striking feature in the organic remains of the Lias, but the *Enaliosaurian* reptiles (*Ichthyopterygia* and *Sauropterygia*), which are extraordinary for their number, size, and structure. Seven genera and 44 species of Reptilia are found in the British Lias. Among the most singular of these are several species of *Ichthyosauri* and *Plesiosauri* (figs. 381, 382). These genera are not confined to this formation, but have been found in strata as high as the White Chalk of England, and as low as the Trias of Germany, a formation which immediately succeeds the Lias in the descending order. It is evident from their fish-like vertebræ, their paddles, resembling those of a porpoise or whale, the length of their tail, and other parts of their structure, that the Ichthyosaurs were aquatic. Their jaws and teeth show that they were carnivorous; and the half-digested remains of fishes and reptiles, found within their skeletons, indicate the precise nature of their food.

Mr. Conybeare gave an ideal restoration of the osteology of this genus, and of that of the *Plesiosaurus*.[6] (See figs. 381,

[4] Agassiz, Poissons Fossiles, vol. iii. tab. C. fig. 1.

[5] Bridgewater Treatise, p. 290.

[6] Geol. Soc. Transactions, Second Series, vol. i. p. 49.

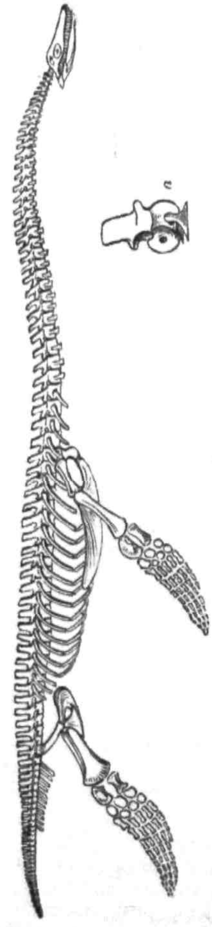
382.) The latter animal had an extremely long neck and small head, with teeth like those of the crocodile, and paddles analo-

Fig. 381.

Skeleton of *Ichthyosaurus communis*, restored by Conybeare and Cuvier.

a. Costal vertebræ.

Fig. 382.



Skeleton of *Plesiosaurus dolichodeirus*, restored by Rev. W. D. Conybeare.

a, Cervical vertebræ.

gous to those of the *Ichthyosaurus*, but larger. It is supposed to have lived in shallow seas and estuaries, and to have breathed

air like the Ichthyosaurus and our modern Cetacea.[7] Some of the reptiles above mentioned were of formidable dimensions. One skeleton of *Ichthyosaurus platyodon*, from the Lias at Lyme, now in the British Museum, must have belonged to an animal more than 24 feet in length; and there are species of *Plesiosaurus* which measure from 18 to 20 feet in length. The form of the *Ichthyosaurus* may have fitted it to cut through the waves like the porpoise; as it was furnished, besides its paddles, with a tail-fin so constructed as to be a powerful organ of motion; but it is supposed that the *Plesiosaurus*, at least the long-necked species, was better suited to fish in shallow creeks and bays defended from heavy breakers.

It is now very generally agreed that these extinct saurians must have inhabited the sea. There are modern examples of marine reptiles. The common crocodile of the Ganges is well known to frequent equally that river and the brackish and salt water near its mouth; and crocodiles are said in like manner to be abundant both in the rivers of the Isla de Pinos (or Isle of Pines), south of Cuba, and in the open sea round the coast. In 1835 a curious lizard (*Amblyrhynchus cristatus*) was discovered by Mr. Darwin in the Galapagos Islands.[8] It was found to be exclusively marine, swimming easily by means of its flattened tail, and subsisting chiefly on seaweed. One of them was sunk from the ship by a heavy weight, and on being drawn up, after an hour, was quite unharmed.

The families of Dinosauria, Crocodilia, and Pterosauria or winged reptiles, are also represented in the Lias.

Sudden destruction of Saurians.—It has been remarked, and truly, that many of the fish and saurians, found fossil in the Lias, must have met with sudden death and immediate burial; and that the destructive operation, whatever may have been its nature, was often repeated.

'Sometimes,' says Dr. Buckland, 'scarcely a single bone or scale has been removed from the place it occupied during life; which could not have happened had the uncovered bodies of these saurians been left, even for a few hours, exposed to putrefaction, and to the attacks of fishes and other smaller animals at the bottom of the sea.'[9] Not only are the skeletons of the Ichthyosaurs entire, but sometimes the contents of their stomachs still remain between their ribs, as before remarked, so that we can discover the form of their excrements and the

[7] Conybeare and De la Beche, Geol. Trans. First Series, vol. v. p. 559; and Buckland, Bridgewater Treatise, p. 203.

[8] See Darwin, Naturalist's Voyage, p. 385. Murray.

[9] Bridgewater Treatise, p. 115.

particular species of fish on which they lived. Not unfrequently there are layers of these coprolites, at different depths in the Lias, at a distance from any entire skeletons of the marine lizards from which they were derived; 'as if,' says Sir H. de la Beche, 'the muddy bottom of the sea received small sudden accessions of matter from time to time, covering up the coprolites and other exuviæ which had accumulated during the intervals.'[1] It is further stated that, at Lyme Regis, those surfaces only of the coprolites which lay uppermost at the bottom of the sea have suffered partial decay from the action of water before they were covered and protected by the muddy sediment that has afterwards permanently enveloped them.

Numerous specimens of a kind of Calamary (*Geoteuthis Bollensis*) have also been met with in the Lower Lias at Lyme, with the ink-bags still distended, containing the ink in a dried state, chiefly composed of carbon, and but slightly impregnated with carbonate of lime. These dibranchiate Cephalopoda, therefore, must, like the saurians, have been soon buried in sediment; for, if long exposed after death, the membrane containing the ink would have decayed.[2]

As we know that river-fish are sometimes stifled, even in their own element, by muddy water during floods, it cannot be doubted that the periodical discharge of large bodies of turbid fresh water into the sea may be still more fatal to marine tribes. In the 'Principles of Geology' I have shown that large quantities of mud and drowned animals have been swept down into the sea by rivers during earthquakes, as in Java in 1699; and that indescribable multitudes of dead fishes have been seen floating on the sea after a discharge of noxious vapours during similar convulsions. But in the intervals between such catastrophes, strata may have accumulated slowly in the sea of the Lias, some being formed chiefly of one description of shell, such as *Ammonites*, others of *Gryphites*.

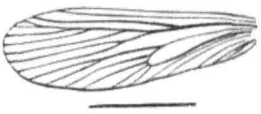
Corals, rare in the Upper and Middle Lias, become frequent in some of the lowest deposits of the Infra-lias, as at Brocastle and Southerndown in South Wales. This group represents the Hettangian of continental geologists.

Freshwater deposits—Insect-beds.—From the above remarks, the reader will infer that the Lias is for the most part a marine deposit. Some members, however, of the series have an estuarine character, and must have been formed within the influence of rivers. At the base of the Upper and Lower Lias respectively, insect-beds appear to be almost everywhere

[1] Geological Researches, p. 334.
[2] Buckland, Bridgewater Treatise, p. 307.

present, throughout the Midland and South-western districts of England. These beds are crowded with the remains of insects, small fish, and crustaceans, with occasional marine shells. One band in Gloucestershire, rarely exceeding a foot in thickness, has been named the 'insect limestone.' It passes upwards, says the Rev. P. B. Brodie,[3] into a shale containing *Cypris* and *Estheria*, and is full of the wing-cases of several genera of Coleoptera, with some nearly entire beetles, of which the eyes are preserved. The nervures of the wings of neuropterous insects (fig. 383) are beautifully perfect in this bed. Ferns, with Cycads and leaves of monocotyledonous plants, and some apparently brackish and freshwater shells, accompany the insects in several places, while in others marine shells predominate, the fossils varying apparently as we examine the bed nearer or farther from the ancient land, or the source whence the fresh water was derived. After studying 300 specimens of these insects from the Lias, Mr. Westwood declares that they comprise both wood-eating and herb-devouring beetles, of the genera *Elater*, *Carabus*, &c., besides grasshoppers (*Gryllus*), and detached wings of dragon-flies and may-flies, or insects referable to the genera *Libellula*, *Ephemera*, *Hemerobius*, and *Panorpa*. The size of the species is usually small, and such as, taken alone, would imply a temperate climate; but many of the associated organic remains of other classes must lead to a different conclusion. At Schambelen, in the canton of Argovia in Switzerland, a rich insect fauna has been brought to light agreeing in general character with the insect-beds of England, but comprising nearly three times the number of species in a very perfect state.

Fig. 383.



Nat. size.

Wing of a neuropterous insect, from the Lower Lias, Gloucestershire. (Rev. P. B. Brodie.)

Fossil plants.—Among the vegetable remains of the Lias, several species of Cycads of the genus *Palæozamia* have been found at Lyme Regis, and the remains of coniferous plants at Whitby, of the genera *Pinites*, *Cupressus* and *Peuce*. M. Ad. Brongniart enumerates forty-seven liassic Acrogens, most of them ferns; and fifty Gymnosperms, of which thirty-nine are Cycads and eleven Coniferæ. Among the Cycads the predominance of *Zamites*, and among the ferns the numerous genera with leaves having reticulated veins (as in fig. 351), are mentioned as botanical characteristics of this era.[4] The absence as yet

[3] A History of Fossil Insects, &c. 1846. London.

[4] Tableau des Vég. Foss. 1849 p. 105.

from the Lias and Oolite of all signs of Dicotyledonous Angiosperms is worthy of notice. Amongst the genera of ferns are *Otopteris*, and *Alethopteris*; and *Equisetetes* are also found.

Origin of the Oolite and Lias.—The entire group of Oolite and Lias consists of repeated alternations of strata of clay, sandstone, and limestone, following each other in the same order. Thus the clays of the Lias are, in ascending order, followed by the Midford sands, and these by the shelly oolitic and pisolitic beds of the Inferior Oolite, succeeded by the oolitic limestone called the Great or Bath Oolite. So, in the Middle Oolite, the Oxford clay is followed by calcareous grit and coral rag; lastly, in the Upper Oolite, the Kimmeridge clay is followed by the Portland sand and limestone.[5] The clay beds, however, as Sir H. de la Beche remarks, can be followed over larger areas than the sand or sandstones.[6] Arenaceous deposits occur with coal and lignite in Yorkshire and Scotland, and resemble a coal-field. In the Alps the strata assume an almost purely calcareous form, the sands and clays being omitted. In some Oolitic districts the clays and intervening limestones retain a uniform character, for distances of from 400 to 600 miles from east to west and north to south.

In order to account for such a succession of strata, we may imagine the bed of the ocean to be at first the receptacle for ages of fine argillaceous sediment, brought by oceanic currents, which may have communicated with rivers, or with part of the sea near a wasting coast. This mud ceases, at length, to be conveyed to the same region, either because the land which had previously suffered denudation is depressed and submerged, or because the current is deflected in another direction by the altered shape of the bed of the ocean and neighbouring dry land. By such changes the water becomes once more clear and fit for the growth of stony zoophytes. Calcareous sand, oolite and pisolite are then formed from comminuted shell and coral, or, in some cases, arenaceous matter replaces the clay; because it commonly happens that the finer sediment, being first drifted farthest from coasts, is subsequently overspread by coarse sand, after the sea has grown shallower, or when the land increasing in extent, whether by upheaval or by sediment filling up parts of the sea, has approached nearer to the spots first occupied by fine mud.

The increased thickness of the limestones in those regions, as in the Alps and Jura, where the clays are comparatively thin, arises from the calcareous matter having been derived from

[5] Conybeare and Philips' Outlines, &c. p. 166.
[6] Geological Researches, p. 337.

species of corals and other organic beings which lived in clear water, far from land, to the growth of which the influx of mud would be unfavourable. Portions, therefore, of these clays and limestones have probably been formed contemporaneously to a greater extent than we can generally prove, for the distinctness of the species of organic beings would be caused by the difference of conditions between the more littoral and the more pelagic areas and the different depths and nature of the sea-bottom. Independently of those ascending and descending movements which have given rise to the superposition of the limestones and clays, and by which the position of land and sea are made in the course of ages to vary, the geologist has the difficult task of allowing for the contemporaneous thinning out in one direction and thickening in another, of the successive organic and inorganic deposits of the same era. On the whole, the Oolitic age was one of slow subsidence over vast areas.

The Lias is well represented in the north and north-west of France, and the British subdivisions occur there. In addition, the equivalents of the Sutton stone and Brocastle deposits, the Hettangian, are well developed, and have a great fauna. This Infra-lias rests conformably on the zone of *Avicula contorta*.

In Switzerland, important insect-beds occur, and in Germany the succession resembles that of England.

CHAPTER XXII.

TRIAS, OR NEW RED SANDSTONE GROUP.

Beds of passage between the Lias and Trias, Rhætic beds and mammifer—Triple division of the Trias Keuper, or Upper Trias of England—Reptiles of the Upper Trias—Footprints in the Bunter formation in England—Dolomitic conglomerate of Bristol—Origin of Red Sandstone and Rock-salt—Precipitation of salt from inland lakes and lagoons—Trias of Germany—Succession—Keuper—St. Cassian and Hallstadt beds—Peculiarity of their fauna—Muschelkalk and its fossils—Trias of the United States—Fossil footprints of birds and reptiles in the valley of the Connecticut—Triassic mammifer of North Carolina—Triassic coal-field of Richmond, Virginia—Indian Trias—The break at the base.

Beds of passage between the Lias and Trias—Rhætic beds.—We have mentioned in the last chapter (p. 315) that the base of the Lower Lias is characterised, both in England and Germany, by beds containing distinct species of Ammonites, the lowest subdivision having been called the zone of *Ammonites planorbis*. Below this zone, on the boundary line between the Lias

and the strata of which we are about to treat, called 'Trias,' there is a group of passage beds extending as a narrow zone of thin strata, from the coast of Yorkshire to Lyme Regis. Patches occur here and there, and especially north and south of the Bristol Channel. These constitute the Rhætic series. Certain cream-coloured limestones are usually found in the West of England, belonging to this series, and were called by William Smith the White Lias, and they have been shown by Mr. Charles Moore to belong to a formation similar to one in the Rhætian Alps of

Fig. 384.

Cardium rhæticum, Merrian. Nat. size. Rhætic Beds.

Fig. 385.

Pecten Valoniensis, Dfr. ½ nat. size. Portrush, Ireland, &c. Rhætic Beds.

Fig. 386.

Avicula contorta, Portlock. Portrush, Ireland, &c. Nat. size. Rhætic Beds.

Bavaria, to which M. Gümbel has applied the name of Rhætic. They have also long been known as the Kössen beds in Germany, and may be regarded as beds of passage between the Lias and Trias. They are named the Penarth beds by the Government surveyors of Great Britain, from Penarth, near Cardiff, in Glamorganshire, where they attain a thickness of fifty feet.

The principal member of this group has been called by Dr. Wright the *Avicula contorta* bed,[1] as this shell is very abundant, and has a wide range in Europe. In Ireland, at Stradneagh, near Portrush, in Antrim, the *Avicula contorta* (fig. 386) is accompanied by *Pecten Valoniensis* (fig. 385) as on the Continent.

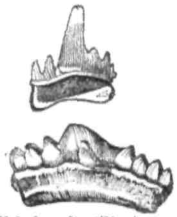
Bone-bed.—The best known member of the group, a thin band of bone-breccia, is conspicuous among the black shales in the neighbourhood of Axmouth in Devonshire, and in the cliffs of Westbury-on-Severn, as well as at Aust and other places on the borders of the Bristol Channel. It abounds in the remains of bones of *Ichthyosaurus* and *Plesiosaurus*, and *Pterodactylus*, and of teeth of fish of the genera *Acrodus*, *Hybodus*, *Gyrolepis*, and *Saurichthys*.

Among those fossils common to the English bone-bed and the Muschelkalk of Germany (p. 338) are the teeth of *Hybodus*

[1] Dr. Wright, on Lias and Bone Bed, Quart. Journ. Geol. Soc. 1860, vol. xvi.

plicatilis (fig. 387), *Saurichthys apicalis* (fig. 388), *Gyrolepis tenuistriatus* (fig. 389), and *G. Albertii*. It may be questioned whether some of those fossils which have a very Triassic character, may not have been derived from the destruction of older strata,

Fig. 387.



Hybodus plicatilis, Agass. Teeth, Bone-bed, Aust and Axmouth.

Fig. 388.

Saurichthys apicalis, Agass. Tooth; natural size and magnified. Axmouth.

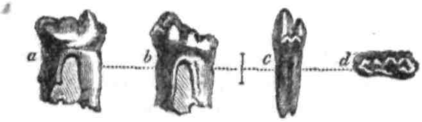
Fig. 389.

Gyrolepis tenuistriatus Agass. Scale: nat. size and magnified. Axmouth.

since in most bone-beds, many of the organic remains are undoubtedly derivative.

Rhætic mammifer.—A remarkable bone-bed occurs in the Rhætic strata of North-Western Germany, and it is filled with shells and the remains of fishes and reptiles, almost all the genera of which, and some even of the species, are the same as those of the subjacent Trias. Professor Plieninger found in it, in 1847, at Diegerloch, about two miles to the south-east of Stuttgart, the molar tooth of a small Marsupial mammal, called by him *Microlestes antiquus*. He inferred its true nature

Fig. 390.



Microlestes antiquus, Plieninger. Molar tooth, magnified. Upper Trias. Diegerloch, near Stuttgart, Würtemberg.

a. View of inner side? *b*. Same, outer side? *c*. Same in profile. *d*. Crown of same.

from its double fangs, and from the form and number of the protuberances or cusps on the flat crown; and considering it as predaceous, probably insectivorous, he called it *Microlestes* from μικρος, little, and ληστης, a beast of prey. Professor W. Boyd Dawkins discovered a molar tooth, which he attributed to a marsupial, *Hypsiprimnopsis Rhæticus*, in the Rhætic beds just below the common bone-bed at Watchet, in Somersetshire. The

late Mr. Charles Moore had previously discovered the same and many other teeth in the contents of a vertical fissure in Carboniferous limestone which had once been covered by fossiliferous Rhætics.

No anatomist had been able to give any satisfactory conjecture as to the affinities of *Microlestes antiquus*, until Dr. Falconer, in 1857, recognised an unmistakable resemblance between its teeth and the two back molars of his new marsupial genus *Plagiaulax* (fig. 306, p. 288), from the Purbeck strata. This would lead us to the conclusion that *Microlestes* was marsupial and plant-eating.

Trias of England.—Beneath the Lias in the Midland and Western counties of England, where the Rhætic beds are absent, there is a great series of red loams, shales, sandstones, and conglomerates, to which the name of the 'New Red Sandstone formation' was first given to distinguish it from other shales and sandstones called the 'Old Red.' These deposits are often identical in mineral character, but they differ greatly in age, the 'Old Red' being of earlier date than the Carboniferous formation. The absence of carbonate of lime, as well as the scarcity of organic remains, together with the bright red colour of most of the rocks of this 'New Red' group, produce a strong contrast between the Trias and the Jurassic formations already described.

The group in question is more fully developed in Germany than in England or France. It has been called the Trias by German writers, or the Triple Group, because it is separable into three distinct formations, called the 'Keuper,' the 'Muschelkalk,' and the 'Bunter-Sandstein.' Of these, the middle division, or the Muschelkalk, is wholly wanting in England, and the uppermost (Keuper) and lowest (Bunter) members of the series are not rich in fossils.

The Keuper.—This upper division is of great thickness in Lancashire and Cheshire, attaining 3,450 feet in this last-mentioned county, and it covers a large extent of country between Lancashire and Devonshire, but it thins out rapidly to less than half its thickness in Staffordshire.

Fig. 391.

Estheria minuta, Bronn. Mag. 2 diams.

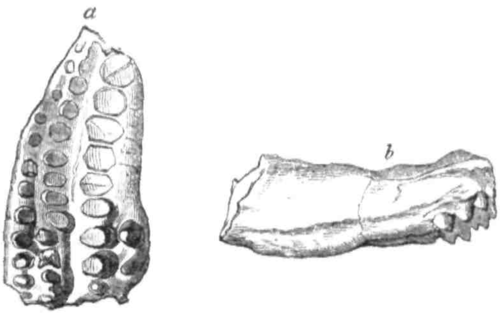
It consists of New Red Marl at the top, with red and grey shales and marls, rock salt and gypsum being important minerals, and it rests on thinly laminated micaceous sandstones and waterstones, with a base of calcareous conglomerate or breccia.

In Worcestershire and Warwickshire, in sandstone belonging to the uppermost part of the Keuper, the bivalve crustacean *Estheria minuta* occurs. The member of the English 'New

Red' containing this shell, in those parts of England, is, according to Sir Roderick Murchison and Mr. Strickland, 600 feet thick, and consists chiefly of red marl or slate, with a band of sandstone. Spines of *Hybodus*, and teeth of other fishes, and footprints of reptiles were observed by the same geologists in these strata.

The remains of four saurians have been found. The one called *Rhynchosaurus* occurred at Grinsell near Shrewsbury, and is characterised by having a small bird-like skull and jaws without teeth, but with a beak. The other three, *Telerpeton*, *Hyperodapedon*, and the crocodilian reptile *Stagonolepis*, were brought to light near Elgin, in strata formerly supposed to belong to the

Fig. 392.



Hyperodapedon Gordoni. Left Palate, Maxillary.
(Showing the two rows of palatal teeth on opposite sides of the jaw.
a. Under surface. *b*. Exterior right side.

Old Red Sandstone, but now recognised as Upper Triassic.[2] The *Hyperodapedon* was afterwards discovered in beds of about the same age, in the neighbourhood of Warwick, and also in South Devon, and remains of the same genus have been found in Central India and Southern Africa, in rocks believed to be of Triassic age. It has been shown by Professor Huxley and Dr. Günther to be a terrestrial reptile having numerous palatal teeth, and closely allied to the living *Sphenodon* of New Zealand.

The recent discovery of this living saurian in New Zealand so closely allied to this supposed extinct division of the Lacertilia seems to afford an illustration of a principle pointed out by Mr. Darwin of the survival in insulated tracts, after many changes in physical geography, of orders of which the congeners have become extinct on continents where they have been

[2] See Judd, Quart. Journ. Geol. Soc. vol. xxix. p. 142, 1873.

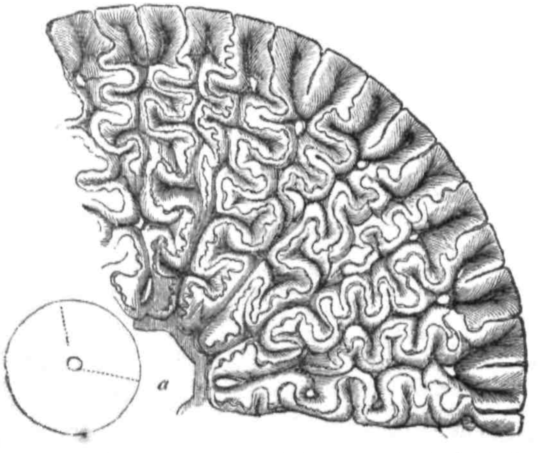
exposed to the severer competition of a larger and progressive fauna.

In 1842 Professor Owen examined, microscopically, some teeth of *Labyrinthodon* (fig. 393), from the Keuper in Warwickshire, and discovered a structure in them of extraordinary complexity.[3] The outside structure of the tooth was found to be disposed in many vertical folds, every alternate fold being several times plaited transversely. A cross section of one of these exhibits a series of convolutions, resembling the labyrinthic windings of the surface of the brain, and from this character Professor Owen has proposed the name *Labyrinthodon* for the new genus. The annexed representation (fig. 394) of part of one is given from his 'Odontography,' plate

Fig. 393.

Tooth of *Labyrinthodon*; nat. size. Warwick sandstone.

Fig. 394.



Transverse section of upper part of tooth of *Labyrinthodon Jaegeri*, Owen (*Mastodonsaurus Jaegeri*, Meyer); natural size, and a segment magnified.
a. Pulp cavity, from which the processes of pulp and dentine radiate.

64 A. The entire length of this tooth is supposed to have been about three inches and a-half, and the breadth at the base one inch and a-half.

This remarkable structure proved on comparison, to characterise not only the genus *Labyrinthodon* but also the allied genus *Mastodonsaurus* of the German Keuper, and other genera

eol. Soc. 2nd series, vol. vi. pl. 2.

now classified under the Labyrinthodontia. The Labyrinthodontia were an extensive order of Amphibia of gigantic dimensions; they appeared in the Carboniferous age, and became extinct in the age of the Upper Trias.

Dolomitic Conglomerate of Bristol.—Near Bristol, and on the flanks of the Mendips, in Somersetshire, and in other counties bordering the Severn, the lowest strata belonging to the Trias, consist of a conglomerate or breccia resting unconformably upon the Old Red Sandstone, and on different members of the Carboniferous rocks such as the Coal Measures, Millstone Grit, and Mountain Limestone. This mode of superposition will be understood by reference to the section below Dundry Hill (fig. 84), where No. 4 is the dolomitic conglomerate. Such breccias may have been partly the result of the subaërial waste of an old land-surface which gradually sank down and suffered littoral denudation in proportion as it became submerged. The pebbles and fragments of older rocks which constitute the conglomerate are cemented together by a red or yellow base of dolomite, and in some places the Encrinites, Corals, Brachiopoda, and other fossils derived from the Mountain Limestone are so detached from the parent rocks that they have the deceptive appearance of belonging to a fauna contemporaneous with the dolomitic beds in which they occur. Layers of Keuper are noticed between masses of the breccia. The embedded fragments are both rounded and angular, some consisting of Carboniferous limestone and Millstone grit, being of vast size, and many weighing nearly a ton. Fractured bones and teeth of saurians which are probably of contemporaneous age have been found in the lower part of the breccia, and two of these, called *Thecodontosaurus*, from the manner in which the teeth were implanted in the jawbone, and *Palæosaurus*, obtained great celebrity because the patches of red conglomerate in which they were found at Durdham Down, near Bristol, were originally supposed to be of Permian or Palæozoic age, and therefore the only representatives in England of vertebrate animals of so high a type in rocks of such antiquity. The teeth of *Thecodontosaurus* are conical, compressed, and with finely serrated edges (see fig. 395); they are referred by Professor Huxley to the Dinosauria.

Fig. 395.

Tooth of *Thecodontosaurus*; 3 times magnified, Riley and Stutchbury, Dolomitic conglomerate. Durdham Down, near Bristol.

The basement beds of the Keuper rest with a slight unconformability, upon an eroded surface of the 'Bunter' next to

It is a general fact, and one not yet accounted for, that scarcely any fossil remains are ever preserved in stratified rocks in which this oxide of iron abounds; and when we find fossils in the New or Old Red Sandstone in England, it is in the gray, and usually calcareous beds that they occur. The saline or gypseous interstratified beds may have been produced by submarine gaseous emanations, or hot mineral springs which often continue to flow in the same spots for ages. Beds of rock salt are, however, more generally attributed to the evaporation of lakes or lagoons communicating at intervals with the ocean. Sir A. Ramsay has remarked in regard to the Trias that it was probably a Continental Period with many inland lakes and seas, the Keuper marls of the British Isles having been deposited in a great lake, fresh or brackish, at the beginning and afterwards rendered salt by evaporation. 'Were the rainfall,' he observes, 'of the area drained by the Jordan to increase gradually, the basin of the Dead Sea would by degrees fill with water, and successive deposits of sediment would gradually overlap each other on the shelving slopes of the lake-basin in which solid salts had previously been deposited. There are examples of this kind of overlap in the New Red Marl of England, in Somerset, Gloucester, Hereford, and Leicester.[6] Sir A. Ramsay suggests that the red peroxide of iron of the sands and clays may in itself be an indication of lacustrine conditions, for each grain of sand and mud is encrusted with a thin pellicle of peroxide of iron, which he thinks could not have taken place in a wide and deep sea.[7] Nevertheless, some of the sands are windborne, as proved by Mr. J. Arthur Philipps, F.R.S.

Major Harris, in his 'Highlands of Ethiopia,' describes a salt lake called the Bahr Assal, near the Abyssinian frontier, which once formed the prolongation of the Gulf of Tadjara, but was afterwards cut off from the gulf by a broad bar of lava. 'Fed by no rivers, and exposed in a burning climate to the unmitigated rays of the sun, it has shrunk into an elliptical basin seven miles in its transverse axis, half filled with smooth water of the deepest cærulean hue, and half with a solid sheet of glittering snow-white salt, the offspring of evaporation.' 'If,' says Mr. Hugh Miller, 'we suppose, instead of a barrier of lava, that sand-bars were raised by the surf on a flat arenaceous coast during a slow and equable sinking of the surface, the waters of the outer gulf might occasionally topple over the bar, and supply fresh brine when the first stock had been exhausted by evaporation.'[8]

[6] Quart. Journ. Geol. Soc. 1871, vol. xxvii. p. 196.

[7] Contemporary Review, July 1873, p. 201.

[8] Hugh Miller, First Impressions of England, 1847, pp. 183, 214.

The Runn of Cutch, as I have shown elsewhere,[9] is a low region near the delta of the Indus, equal in extent to about a quarter of Ireland, which is neither land nor sea, being dry during part of every year, and covered by salt water during the monsoons. Here and there its surface is encrusted over with a layer of salt caused by the evaporation of sea water. A subsiding movement has been witnessed in this country during earthquakes, so that a great thickness of pure salt might result from a continuation of such sinking.

NOMENCLATURE OF TRIAS.

German	French	English
Keuper	Marnes irisées	Red and grey saliferous and gypseous shales and sandstone, with rock salt. Dolomitic conglomerate.
Muschelkalk	Muschelkalk, ou calcaire coquillier	Wanting in England.
Bunter-Sandstein.	Grès bigarré	Red sandstone and pebble beds and quartzose conglomerate. Soft red sandstones.

Trias of Germany.—In Germany, as before noticed (p. 328), the Trias first received its name as a Triple Group, consisting of two sandstones with an intermediate marine calcareous formation, which last is wanting in England.

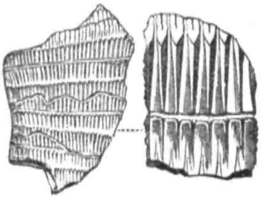
German Trias.—The succession of strata in the great German Triassic basin is—Upper Trias or Keuper, with red marls, plant beds, gypsum, and rock-salt, overlying the Letten Kohle, with *Voltzia*, *Estheria minuta*, the Labyrinthodont *Mastodontosaurus*, and the *Ceratodus* fish. Then comes the Muschelkalk, with limestones, with *Myophoria*, *Ceratites*, and *Encrinus liliiformis*, followed by Bunter, with red and green marls and coarse sandstones, with *Voltzia*, *Estheria*, and *Myophoria*.

The plants of the Trias belong partly to Coniferæ, the genus *Voltzia*, with its cypress-like twigs, being characteristic. The genus *Albertia* is also represented. Ferns were numerous: genera, *Pecopteris*, *Cyclopteris*, *Anomopteris*, *Acrostichites*, *Clathropteris*,

[9] Principles of Geology, chap. xxvii.

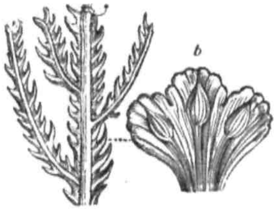
Sagenopteris, *Tæniopteris*, &c. Cycads, *Pterophyllum*, *Zamites*, *Pseudozamites*, *Podozamites*, and *Otozamites*. These last prevailed extensively, and have given the term 'Age of Cycads' to

Fig. 398.



Equisetum arenaceum. Fragment of stem, and a small portion of same magnified. Keuper.

Fig. 399.



a. Voltzia heterophylla. (Syn. *Voltzia brevifolia.*)
b. Portion of same magnified to show fructification. Sulzbad. Bunter-Sandstein.

the Trias. A true *Equisetum* exists, and an ally, the genus *Schizoneura*.

Alpine Trias.—The Trias is grandly developed in the Eastern Alps. Including the Rhætic beds, the following is the succession of the great groups of strata.

The Rhætic group, consisting of marine limestones, dolomites, and rarely, shales : 1. Kössen beds and Azarolla beds, with corals, *Brachiopoda*, and *Lamellibranchiata*, such as *Gervillia*. 2. Dachstein limestone, with large forms of *Megalodon* or the Dachstein bivalve, numerous corals, and *Brachiopoda*. 3. Dolomites. A pale well-bedded finely crystalline rock, usually without fossils.

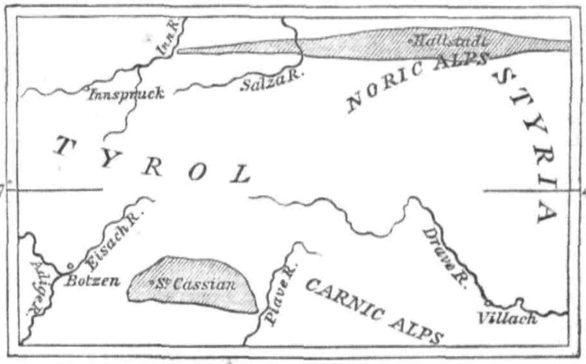
Upper Trias : 1. Cardita beds and Raibl beds, shales, marls with plants, *Crustacea*, *Cephalopoda*, and fish. 2. Hallstadt limestone and Esino beds, red and mottled marbles and limestones, with many *Cephalopoda* and large *Gasteropoda*. The Schlern Dolomite, 3,820 feet thick, forming picturesque mountains. 3. Lunz beds, containing coal plants, and forming the only freshwater group. 4. Zlambach coral beds. 5. St. Cassian beds—calcareous marls of South Tyrol, with *Ammonites*, *Gasteropoda*, *Lamellibranchiata*, *Brachiopoda*, *Crinoidea*, *Echinoidea*, and *Corals*. 6. *Halobia Lommelii* beds. Then comes the Lower Trias : 7. Alpine Muschelkalk, limestones, and dolomites, with lower strata containing *Ceratites*.

And these are equivalent to the Upper Division of the Bunter.

German Keuper.—The sandstones of the Keuper of England, France, and Germany, containing the remains of

plants, reptilia, and very few marine organisms, accumulated whilst the Triassic sea of the Alpine region was depositing thick marine limestones, of which those of Hallstadt, north of the Alps, are the types. Huge *Ammonites* characterise these

Fig. 400.

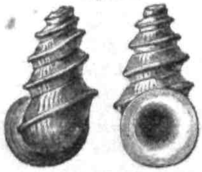


Map showing the position of St. Cassian and Hallstadt areas.

deposits. On the south of the Tyrol the St. Cassian beds were forming a little earlier, and the fauna was rich in the extreme. The following are characteristic genera—*Scoliostoma* (fig. 401), *Platystoma* (fig. 402), and *Koninckia* (fig. 403).

Ammonites and *Orthoceratites* occur in the St. Cassian and Hallstadt beds. As the Orthocerata, which are common in some

Fig. 401.



Scoliostoma, St. Cassian.

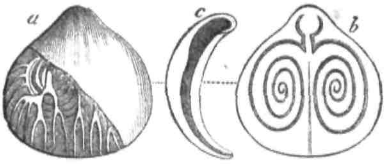
Fig. 402.

Platystoma Suessii, Hörnes.
From Hallstadt.

palæozoic rocks, had never been met with in the Muschelkalk of the Lower Trias, much surprise was felt that seven or eight species of the genus should appear in the Hallstadt beds of the Upper Trias. Some are of large dimensions, and are associated with large *Ammonites* with foliated lobes, a form never seen before so low in the Mesozoic series. *Cerithium*, so abundant in tertiary strata, and which still exists, is represented by no less than fourteen species.

A rich fauna, comprising 225 species, of which about one-fourth are identical with those of St. Cassian, has been brought to light at D'Esino, in Lombardy, and has been admirably illustrated by Professor Stoppani.[1] He describes 65 species of the genus of spiral univalve *Chemnitsia*, reminding us by its abun-

Fig. 403.



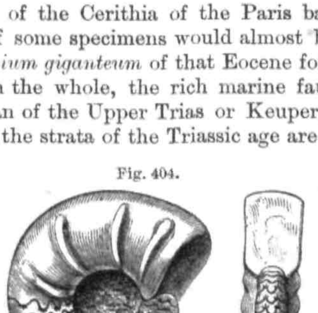
Koninckia Leonhardi, Wissmann.

a. Ventral view. Part of ventral valve removed to show the vascular impressions of dorsal valve.
b. Interior of dorsal valve, showing spiral processes restored.
c. Vertical section of both valves. Part shaded black showing place occupied by the animal, and the dorsal valve following the curve of the ventral.

dance of the Cerithia of the Paris basin, while the enormous size of some specimens would almost bear comparison with the *Cerithium giganteum* of that Eocene formation.

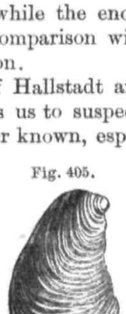
On the whole, the rich marine fauna of Hallstadt and St. Cassian of the Upper Trias or Keuper, leads us to suspect that when the strata of the Triassic age are better known, especially

Fig. 404.



Ceratites nodosus, Schloth, ½. Muschelkalk, Germany. Side and front view, showing the peculiar outline of the septa dividing the chambers.

Fig. 405.



Gervillia (*Avicula*) *socialis*. Schloth, nat. size. Found in the Muschelkalk and Keuper.

those belonging to the period of the Bunter Sandstone, the break between the Palæozoic and Mesozoic Periods may be much diminished.

Muschelkalk.—It consists chiefly of a compact greyish limestone, but includes beds of dolomite in many places, together with gypsum and rock salt and clays. This limestone—

[1] Stoppani, Les Pétrifactions d'Esino. Milan, 1858–1860.

a formation, perhaps, wholly unrepresented in England—abounds in fossil shells, as the name implies. Among the

Fig. 406.

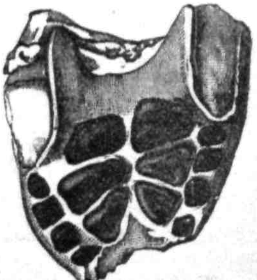
Encrinus liliiformis, Schloth. Syn. *E. moniliformis*, ⅔. Body, arms, and part of stem.
a. Section of stem. Muschelkalk.

Fig. 407.

Aspidura loricata, Agass.
a. Upper side. *b*. Lower side.
Muschelkalk.

Cephalopoda there are no *Belemnites*, and no *Ammonites* with completely foliated sutures, as in the Lias and Oolite and the Hallstadt beds; but the genus *Ceratites*, De Haan, is present, in which the lobes of the sutures seen on the shell are denticulated or crenulated whilst the 'saddles' are simply rounded. Among the bivalve crustacea, the *Estheria minuta*, Bronn (fig. 391), is abundant, ranging through the Keuper and Muschelkalk; and *Gervillia socialis* (fig. 405), having a similar range, is found in great numbers in the Muschelkalk of Germany, France, and Poland.

Fig. 408.



Palatal teeth of *Placodus gigas*.
Muschelkalk.

The abundance of the heads and stems of lily encrinites, *Encrinus liliiformis* (fig. 406), shows the slow manner in which some beds of this limestone have

been formed in clear sea water. The star-fish called *Aspidura loricata* (fig. 407) is as yet peculiar to the Muschelkalk. In the same formation are found the skull and teeth of the genus *Placodus* (see fig. 408). Perfect specimens enabled Professor Owen, in 1858, to show that this fossil was a Saurian, which probably fed on shell-bearing molluscs, and used its short and flat teeth, so thickly coated with enamel, for pounding and crushing the shells.

Bunter-sandstein.—The *Bunter-sandstein* consists of various-coloured sandstones, dolomites, and red clays, with some beds, especially in the Hartz, of calcareous pisolite or roe-stone, the whole sometimes attaining a thickness of more than 1,000 feet. The sandstone of the Vosges is proved, by its fossils, to belong to this lowest member of the Triassic group. At Sulzbad (or Saultz-les-Bains), near Strasburg, on the flanks of the Vosges, many plants have been obtained from the 'Bunter,' especially conifers of the extinct genus *Voltzia*, of which the fructification has been preserved. (See fig. 399.) Out of thirty species of ferns, cycads, conifers, and other plants, enumerated by M. Ad. Brongniart, in 1849, as coming from the 'Grès Bigarré,' or Bunter, not one is common to the Keuper.

The footprints of *Labyrinthodon* observed in the clays of this formation at Hildburghausen, in Saxony, have already been mentioned. Some idea of the variety and importance of the terrestrial vertebrate fauna of the three members of the Trias in Northern Germany may be derived from the fact that in the great monograph by the late Hermann von Meyer on the reptiles of the Trias, the remains of no less than eighty distinct species are described and figured.

Trias of North America.—The formation covers an immense area, and may be divided into the Eastern and Western series. The former are freshwater and terrestrial accumulations, and the latter are marine deposits. In the Eastern area the valley of the Connecticut river offers a type. In a depression of the granitic or hypogene rocks in the States of Massachusetts and Connecticut, strata of red sandstone, shale, and conglomerate are found, occupying an area more than 150 miles in length from north to south, and about 5 to 10 miles in breadth, the beds dipping to the eastward at angles varying from 5 to 50 degrees. Having examined this series of rocks in many places, I feel satisfied that they were formed in shallow water, and for the most part near the shore, and that some of the beds were from time to time raised above the level of the water, and laid dry, while a newer series, composed of similar sediment, was forming.

The footprints of no less than 50 species of Labyrinthodonts have been detected in these rocks. The tracks have been found in more than twenty places, scattered through an extent of nearly 80 miles from north to south, and they are repeated through a succession of beds attaining at some points a thickness of more than 1,000 feet.

Fig. 409.

Footprints of a Dinosaur (?). Turner's Falls, Valley of the Connecticut.

Some of the footprints, which resemble those of long-legged birds, were probably those of Dinosauria.

In North Carolina a small marsupial animal lived during the Trias, and its remains have been discovered by Emmons. It is of an insectivorous species, and is called *Dromatherium Sylvestre*, and is the oldest mammal of the New World.

The age of the Connecticut beds cannot be proved by direct superposition, but may be presumed from the general structure of the country. That structure shows them to be newer than the movements to which the Appalachian or Alleghany chain owes its flexures, and this chain includes the ancient or palæozoic Coal-formation among its contorted rocks.

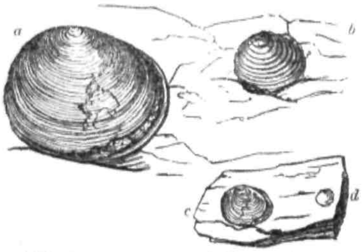
Coal-field of Richmond, Virginia.—In the State of Virginia, at the distance of about 13 miles eastward of Richmond, the capital of that State, there is a Coal-field occurring in a depression of the granite rocks, and occupying a geological position analogous to that of the New Red Sandstone, above mentioned, of the Connecticut Valley. It extends 26 miles from north to south, and from 4 to 12 from east to west.

The plants consist chiefly of *Zamites*, *Equisitacea*, and ferns, and were considered by Heer, to have the nearest affinity to those of the European Keuper.

The *Equisetæ* are very commonly met with in a vertical position more or less compressed. It is clear that they grew in the places where they are now found, buried in strata of hardened sand and mud. I found them maintaining their erect attitude, at points many miles apart, in beds both above and between the seams of coal. In order to explain this fact we must suppose such shales and sandstones to have been gradually accumulated during the slow and repeated subsidence of the whole region.

The fossil fish are Ganoids, some of them of the genus *Catopterus*, others belonging to the liassic genus *Tetragonolepis* (*Æchmodus*) (see fig. 377, p. 318). Amongst the Crustacea, two species of *Entomostraca* called *Estheria* are in such profusion, in some shaly beds, as to divide them like the plates of mica in micaceous shales (see fig. 410).

Fig. 410.



a. Estheria ovata. *b.* Young of same.
c. Natural size of *a.* *d.* Natural size of *b.*
Triassic coal-shale, Richmond, Virginia.

These Virginian Coal-measures are composed of grits, sandstones, and shales, closely resembling those of palæozoic date in America and Europe; and the measures rival those of the last-named continent in the thickness of the coal-seams. One of these, the main seam, is in some places from 30 to 40 feet thick, and is composed of bituminous coal.

The *Dromatherium*, just alluded to, is at least as ancient as the Microlestes of the European Rhætic, described p. 327; and the fact is highly important, as proving that a certain low grade of marsupials had not only a wide range, in time, from the Trias to the Purbeck of Europe, but had also a wide range in space, namely, from Europe to North America, in an east and west direction, and, in regard to latitude, from Stonesfield, in 52° N., to that of North Carolina, in 35° N.

If the three localities in Europe where the most ancient mammalia have been found—Purbeck, Stonesfield, and Stuttgart—had belonged all of them to formations of the same age, we might well have imagined so limited an area to have been peopled exclusively with pouched quadrupeds, just as Australia [2] now is, while other parts of the globe were inhabited by placental, or ordinary Mammalia. But the great difference of age of the strata in each of these three localities, seems to indicate the predominance throughout a vast lapse of time (from the era of the Upper Trias to that of the Purbeck beds) of a low grade of Mammalia; and there must also have been a vast extension in geographical area of the marsupials during that portion of

[2] Australia now supports one hundred and sixty species of marsupials, while the rest of the continents and islands are tenanted by about seventeen hundred species of Mammalia, of which only forty-six are marsupial, and these are of a different family to the marsupials of Australia—namely, the opossums of North and South America.

the Secondary or Mesozoic epoch which has been termed 'the age of reptiles.' The predominance in earlier ages of these Mammalia of a low grade, and the absence, so far as our investigations have yet gone, of species of higher organisation, whether aquatic or terrestrial, is certainly in favour of the theory of progressive development.

Trias of India.—There is a marine Trias in the Himalaya and in Baluchistan with Muschelkalk and St. Cassian species in it. But the great development is in the peninsula, where the terrestrial remains of the period, form vast coal-beds and shales and clays with plants and animals. Some of the lower beds may belong to the Permian age. In Australia, in New South Wales, Victoria, and Queensland, are important Triassic coal-bearing strata.

Among the genera of plants common to this age in Hindostan and Australia were *Cyclopteris*, *Glossopteris*, *Tæniopteris*, *Gangamopteris*, *Schizoneura*, *Sphenopteris*, *Zamites*, *Palæozamia*.

It is a very remarkable fact that, although the base of the Triassic rocks is not always readily separable from the Palæozoic formation beneath, there is a vast palæontological break between them.

The Mesozoic age commenced when the first deposits of the Trias accumulated, and many hundreds of species common in the lower rocks ceased to exist, whilst a great marine fauna soon prevailed, and of an almost totally different kind to that which previously existed. The plants of the Mesozoic age were foreshadowed in the Palæozoic, and some genera persisted into the Trias, but the majority ceased to exist. Some of the lower forms of invertebrate life persisted through the great change in the physical geography of the world which commenced at the close of the Carboniferous age, was considerable during the Permian, and great at its close. Of the corals, not a genus or species lived on, and many new genera are found in the marine Trias. *Nautilus* and *Orthoceratites* lived on as genera, and *Ammonites* commenced (possibly earlier in India). A great change occurred in the Mollusca and Crustacea. The Labyrinthodontia persisted, and many genera of Ganoid fish. But the number of genera which passed from the Palæozoic to the Mesozoic of all kinds, animals and plants, was small.

PRIMARY OR PALÆOZOIC SERIES.

CHAPTER XXIII.

PERMIAN OR MAGNESIAN LIMESTONE GROUP.

Line of separation between Mesozoic and Palæozoic rocks—Distinctness of Triassic and Permian groups—Term Permian—Thickness of calcareous and sedimentary rocks in North of England—Upper, Middle, and Lower Permian—Marine shells and corals of the English Magnesian Limestone—Reptiles and fish of Permian marl slate—Footprints of reptiles—Angular breccias in Lower Permian—Permian rocks of the Continent—Zechstein and Rothliegendes of Thuringia—Permian of Russia—Permian flora—Its affinity with the Carboniferous—The Permo-Carboniferous of Pilsen.

IN pursuing our examination of the strata, in descending order, we have next to pass from the base of the Secondary or Mesozoic to the uppermost or newest of the Primary or Palæozoic formations. As this point has been selected as a line of demarcation for one of the three great divisions of the fossiliferous series, the student might naturally expect that by aid of lithological and palæontological characters, he would be able to recognise a distinct break between the newer and older group, without difficulty. The distinctions between the Trias and the underlying Permian are very evident in some Continental localities, yet, owing to the sameness of mineral constitution and the rarity of fossils, the break is not very apparent in England. But it has at length been made clear that the older or Permian rocks are more connected with the Primary or Palæozoic than with the Secondary or Mesozoic strata already described.

The term Permian was proposed for this group by Sir R. Murchison, from Perm, a Russian province, where it occupies an area twice the size of France and contains a great abundance and variety of fossils both vertebrate and invertebrate. In Germany the term Dyas has been used on account of the two great divisions of the formation which are found there. Pro-

fessor Sedgwick in 1832[1] described what is now recognised as the central member of this group, the Magnesian Limestone, showing that it attained a thickness of 600 feet along the north-east of England, in the counties of Durham, Yorkshire, and Nottinghamshire, its lower part often passing into a fossiliferous marl-slate, and resting on an inferior Red Sandstone, the equivalent of the Rothliegendes of Germany. It appears from the observations of Mr. Binney, Sir R. Murchison, Mr. Harkness, and others, that it is in the region where the limestone is most largely developed, as for example in the county of Durham, that the associated red sandstones or sedimentary rocks are thinnest, whereas in the country where the latter are thickest the calcareous member is reduced to 30 or even sometimes to 10 feet.

Mr. Hull gives the following depths :—

THICKNESS OF PERMIAN STRATA IN NORTH OF ENGLAND.

	N.W. of England, feet.	N.E. of England. feet.
Upper Permian (Red sandstones and clays) . . .	600	50–100
Middle ,, (Magnesian limestone)	10–30	600
Lower ,, (Red and variegated sandstones, &c.) .	3,000	100–250[2]

Upper Permian.—What is called in this table, the Upper Permian, will be seen to attain its chief thickness in the north-west or on the coast of Cumberland, as at St. Bees' Head, where it is described by Sir Roderick Murchison as consisting of red sandstones and red clays with gypsum resting on a thin course of Magnesian Limestone with fossils, which again is connected with the Lower Red Sandstones, resembling the Upper one in such a manner that the whole forms a continuous series. No fossil footprints have been found in this Upper, although they have been in the Lower Sandstone.

Middle Permian—Magnesian Limestone and Marl-slate.—This formation is seen upon the coast of Durham and Yorkshire, between the Wear and the Tees. Among its characteristic fossils are *Schizodus Schlotheimi* (fig. 411) and *Mytilus septifer* (fig. 413). These shells occur at Hartlepool and Sunderland, where the rock assumes an oolitic and botryoidal character. Some of the beds in this division are ripple-marked. In some parts of the coast of Durham, where the rock is not crystalline,

[1] Trans. Geol. Soc. Lond. Second Series, vol. iii. p. 37.

[2] Edward Hull, Ternary Classification, Quart. Journ. of Science, 1869, No. xxiii.

it contains as much as 44 per cent. of carbonate of magnesia, mixed with carbonate of lime. In other places—for it is extremely variable in structure—it consists chiefly of carbonate of lime, and has concreted into globular and hemispherical

Fig. 411.

Schizodus Schlotheimi, Geinitz, ⅔. Permian crystalline limestone.

Fig. 412.

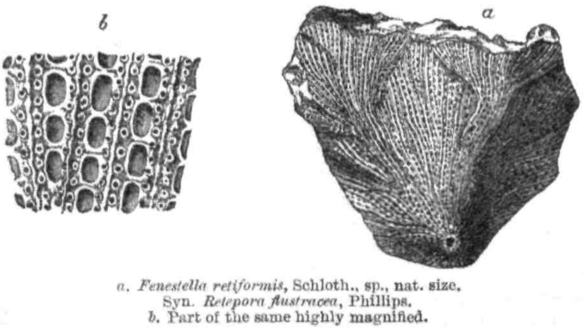
The hinge of *Schizodus truncatus*, King. Permian.

Fig. 413.

Mytilus septifer, King. Syn. *Modiola acuminata*, Sow., nat. size. Permian crystalline limestone.

masses, varying from the size of a marble to that of a cannon-ball, and radiating from the centre. Occasionally earthy and pulverulent beds pass into compact limestone or hard granular dolomite. Sometimes the limestone appears in a brecciated form, the fragments which are united together not consisting of foreign rocks, but seemingly composed of the breaking-up of the

Fig. 414.



a. *Fenestella retiformis*, Schloth., sp., nat. size.
Syn. *Retepora flustracea*, Phillips.
b. Part of the same highly magnified.
Magnesian Limestone, Humbleton Hill, near Sunderland.[3]

Permian limestone itself, about the time of its consolidation. Some of the angular masses in Tynemouth Cliff are 2 feet in diameter.

The magnesian limestone sometimes becomes fossiliferous and includes in it delicate Bryozoa, one of which, *Fenestella retiformis* (fig. 414), is a very variable species, and has received many different names. It sometimes attains a large size, single

[3] King's Monograph, Pal. Soc. Lond. Pl. 2.

specimens measuring 8 inches in width. This Bryozoan, and four other species, are common to England and the Permian of Germany.

The total known fauna of the Permian series of Europe at present numbers 300 species, of which more than half are mollusca. Not one of these is common to rocks newer than the Palæozoic, and the Brachiopoda are the only group which have furnished species common to the more ancient or Carboniferous rocks. There are few Gasteropods. The Cephalopoda are, *Nautilus Freieslebeni*, found also in the German Zechstein, and species of *Orthoceras*.

With regard to the Brachiopoda, shells of the genera *Productus* (fig. 415) and *Strophalosia* (the latter of allied form with hinge teeth), which do not occur in strata newer than the

Fig. 415.

Productus horridus, Sowerby, ½. (*P. Calvus*, Sow.) Sunderland and Durham, in Magnesian Limestone. Zechstein and Kupfer-schiefer, Germany.

Fig. 416.

Lingula Credneri. (Geinitz.) Magnesian Limestone and Carboniferous. Marl-slate, Durham; Zechstein, Thuringia.

Fig. 417.

Spirifera alata, Schloth., ⅘. Syn. *Trigonotreta undulata*, Sow. King's Monogr. Magnesian limestone.

Permian, are abundant in the ordinary yellow magnesian limestone. They are accompanied by certain species of *Spirifera* (fig. 417), and *Lingula Credneri* (fig. 416). Some of the Permian Brachiopoda, such as *Camarophoria* allied to *Rhynchonella*, *Spiriferina*, and two species of *Lingula*, are specifically the same as some fossils of the Carboniferous rocks. *Avicula*, *Arca*, and *Schizodus* (fig. 411), and other lamellibranchiate bivalves, are abundant.

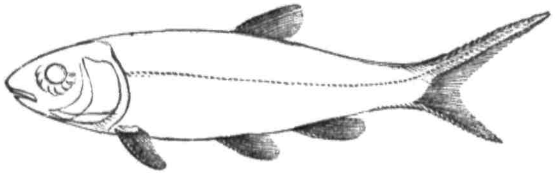
The Magnesian Limestone has yielded, in England, only 100 species of fossils, of which the Brachiopoda number 21, the Lamellibranchs 31, the Gasteropoda 26, and fish 21 species.

Beneath the limestone lies a formation termed the marl-slate, which consists of hard, calcareous shales, marl-slate and thin-bedded limestones. At East Thickley, in Durham, where it is thirty feet thick, this slate has yielded many fine specimens of fossil fish—of the genera *Palæoniscus* 10 species, *Pygopterus* 2 species, *Cœlacanthus* 2 species, and *Platysomus* 2 species, which as genera are common to the older Carboniferous formation; but the Permian species are peculiar, and, for the most part,

identical with those found in the Marl-slate or Copper-slate of Thuringia.

The *Palæoniscus* above mentioned belongs to that division of fishes which M. Agassiz has called 'Heterocercal,' which usually have their tails unequally bilobate, like the recent Shark and Sturgeon, and the vertebral column running along the upper

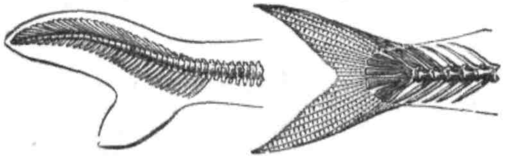
Fig. 418.



Restored outline of a fish of the genus *Palæoniscus*, Agass.

caudal lobe. (See fig. 418.) The 'Homocercal' fish, which comprise almost all the vast number of species at present known living, have the tail-fin either single or equally divided; and the vertebral column stops short, and is not prolonged into either lobe. (See fig. 420.) Now it is a singular fact, first

Fig. 419. Fig. 420.



Shark. *Heterocercal.* Shad. (*Clupea.* Herring tribe.) *Homocercal.*

pointed out by Agassiz, that the heterocercal form, which is confined to a small number of existing genera, is universal in the Magnesian Limestone and all the more ancient formations. It characterises the earlier periods of the earth's history, whereas in the secondary strata, or those newer than the Permian, the homocercal tail greatly predominates.

In Professor King's monograph before referred to, a full description has been given by Sir Philip Egerton of the species of fish characteristic of the marl-slate; and figures of the ichthyolites, which are very entire and well preserved, will be found in the same memoir. Even a single scale is usually so characteristically marked as to indicate the genus, and sometimes even the particular species. They are often scattered through the beds

singly, and may be useful to the geologist, in determining the age of the rock.

SCALES OF FISH. MAGNESIAN LIMESTONE.

Fig. 421.

Fig. 422.

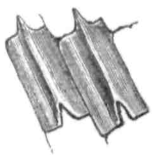


Fig. 423.

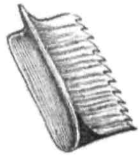
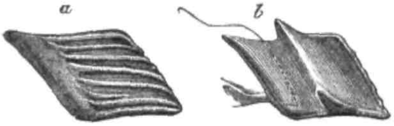


Fig. 424.

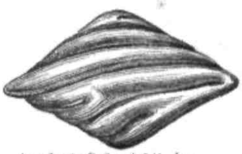
Fig. 421. *Palæoniscus comptus*, Agassiz. Ganoid scale, magnified. Marl-slate.
Fig. 422. *Palæoniscus elegans*, Sedg. Under surface of ganoid scale, magnified. Marl-slate.
Fig. 423. *Palæoniscus glaphyrus*, Ag. Under surface of ganoid scale, magnified. Marl-slate.
Fig. 424. *Cœlacanthus granulatus*, Ag. Granulated surface of scale, magnified. Marl-slate.

Fig. 425.



Pygopterus mandibularis, Ag. Marl-slate.
a. Outside of scale, magnified.
b. Under surface of same.

Fig. 426.



Acrolepis Sedgwickii, Ag.
Outside of scale, magnified.
Marl-slate.

Two species of *Protorosaurus*, a genus of reptiles, have been discovered in the marl-slate, one representative of which, *P. Speneri*, has been celebrated ever since the year 1810 as characteristic of the Kupfer-schiefer or Permian of Thuringia. Professor Huxley informs us that the agreement of one of the Durham fossils with Hermann von Meyer's figure of the German specimen is most striking. Although the head is wanting in all the examples yet found, they clearly belong to the Lacertian order. Remains of a Labyrinthodont, *Lepidotosaurus Duffi*,[4] have been met with in the same slate near Durham; and a quarry in the Permian sandstone of Kenilworth has yielded the skull of another species, called by Professor Huxley *L. Dasyceps*, on account of the roughness of the surface of the cranium.

Lower Permian.—The principal development of Lower Permian is, as we have seen by Mr. Hull's table (p. 345), in the north-west, where the Penrith sandstone, as it has been called,

[4] Hancock and Howse, Quart. Geol. Journ. vol. xxvi. pl. xxxviii.

and the associated breccias and purple shades are estimated by Professor Harkness to attain a thickness of 3,000 feet. Organic remains are generally wanting, foot-prints and worm-tracks are occasionally met with, and the leaves, cones, and wood of coniferous plants have been found in beds considered by Professor Harkness to be the equivalent of the Marl-slate which overlies the Penrith sands at Hilton. Also in the red sandstones of Corncockle Muir near Dumfries very distinct footprints of Labyrinthodontia occur. No bones of the animals which they represent have yet been discovered, but a cranium of *Dasyceps* has been found further south.

Angular Breccias in Lower Permian.—A striking feature in these beds is the occasional occurrence, especially at the base of the formation, of angular and sometimes rounded fragments of Carboniferous and older rocks of the adjoining districts. These are included in a red matrix. Some of the angular masses are of huge size. These brecciated conglomerates are well seen in the Abberley Hills, where they are 400 feet thick.

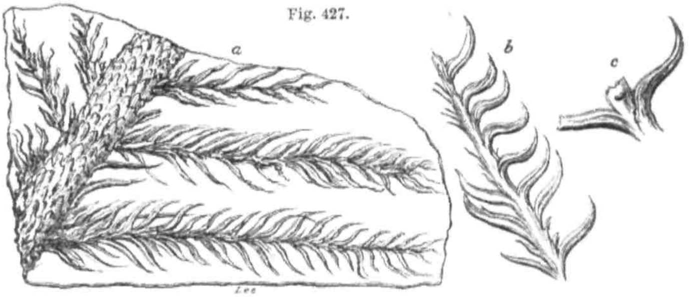
Sir A. Ramsay refers the angular form and large size of the fragments composing these breccias, to the action of floating ice in the sea. These masses of angular rock, some of them weighing more than half a ton, and lying confusedly in a red unstratified marl, like stones in boulder drift, are in some cases polished, striated, and furrowed like erratic blocks in the moraine of a glacier. They can be shown, in some instances, to have travelled from the parent rocks, thirty or more miles distant, and yet not to have lost their angular shape.

Germany.—The Permian is well seen on the flank of the Harz, in Thuringia, Saxony, Bavaria, and Bohemia, and has been called Dyas from there being two types of strata in it. First—a Zechstein group on the top, with a clayey, thin-bedded limestone, having beds of gypsum, rock-salt, and bituminous shales and limestones above, and Kupfer-schiefer, a black bituminous shale containing copper ores and a conglomerate, beneath it. Second—a Rothtodtliegende (or red dead layer), which is divided into three groups: Upper—conglomerates and volcanic remains; Middle—red clays and sandstones and volcanic interstratified deposits; and Lower—shales and sandstones, with bituminous bands and conglomerates. These lower strata are 6,000 feet thick in Bavaria, and are very unfossiliferous. Coniferous trees are present, however, low down, and form, with other plants, a coal seam in the Mansfeld district. The plants are of the same genera as those of the Carboniferous, but belong to different species.

The Zechstein group is fossiliferous, and the copper-bearing series contains numerous fish and mollusca. The term Roth-

todtliegende refers to the rocks being red, and dead as regards copper yielding.

Fig. 427.



Walchia piniformis, Schloth. Permian, Saxony. (Gutbier, Die Versteinerungen des Permischen Systemes in Sachsen, vol. ii. pl. x.) Nat. size.
a. Branch. *b*. Twig of the same. *c*. Leaf magnified.

In Russia the nearly horizontal strata of the Permian, cover vast areas, and consist of sandstones, marls, shales, and thin seams of coal, conglomerates, limestones, and rock-salt and gypsum beds. In the lower half of the strata *Calamites*, *Cyclopteris*, and *Pecopteris* appear. *Palæoniscus* and Labyrinthodonts have been found, and the marine beds contain *Productus horridus* and *Productus cancrini*.

Permian Flora.—About 18 or 20 species of plants are known in the Permian rocks of England. None of them pass down into the Carboniferous series, but several genera, such as *Alethopteris*, *Neuropteris*, and *Walchia*, are common to the two groups. *Caulopteris*, *Lepidodendron*, *Calamites*, and *Sternbergia* are lower Permian and Carboniferous genera, and fragments of coniferous wood have been found with them. The Permian flora on the Continent appears, from the researches of MM. Murchison and De Verneuil in Russia, and of MM. Geinitz and Von Gutbier in Saxony, to be moderately distinct from that of the Coal, 50 species being

Fig. 428.

Cardiocarpon Ottonis. Gutbier. Permian, Saxony. ½ diameter.

Fig. 429.

Noeggerathia cuneifolia. Brongniart.[5]

[5] Murchison's Russia, vol. ii. pl. A, fig. 3.

The Millstone grits were the wear and tear of arenaceous rocks and granites, and the mountain limestones and shales beneath, were marine deposits composed of the remains of Foraminifera, Testacea, Crinoidea, Corals, &c.

In the south-western part of England, in Somersetshire and South Wales, the three divisions of the Carboniferous formation are—

1. Coal measures	Upper series of sandstones, shales, and 26 coal-seams. Pennant grit and 15 coal-seams. Lower coal-measures with ironstone and 34 coal-seams.
2. Millstone grit	A coarse quartzose sandstone used for millstones. 400 feet shale called Farewell Rock.
3. Carboniferous or Mountain limestone	A calcareous rock containing marine shells, corals, and encrinites. Thickness variable: 2,000 feet. Lower limestone shale 400 feet.

These divisions are indicated upon the diagram, fig. 84, p. 99; but the position of the Lower limestone shale is at the base of the limestone.

General Notice of the Divisions.—The coal-measures of the North of England differ, to a certain extent, from those of the south-west; but a typical series would include the following strata. Top. 1. Red and grey sandstones, clays, and sometimes breccias, with occasional coal-seams and streaks of coal and *Spirorbis* limestone with *Cythere inflata*. 2. Middle coals, yellow sandstones, clays, and shales, with numerous workable coal-seams resting on fire-clays: fossils, *Anthracosia*, *Anthracomya*, *Beyrichia*, *Estheria*, *Spirorbis*. 3. Lower beds, gannister beds, flagstones, shales and thin coals, with hard siliceous layers beneath the coal-seams. Flagstones intercalated. Fossils, *Aviculopecten*, *Lingula*, *Goniatites*, *Orthoceras*. Bone-bed, with fish and Labyrinthodonts.

In Scotland the equivalents of the uppermost beds above mentioned, are probably a red sandstone group without coals, overlying workable (flat) coals; and in the North-west of England these beds are barren here and there, as at Wigan; but at Manchester they are important and coal bearing. At Burnley, on the other hand, the beds are absent.

The Millstone grit, well seen in South Wales, is grandly developed beneath some Coal-measures, and feebly beneath others, or it may be wanting. For along a line drawn from Shropshire through South Staffordshire, Leicestershire, to the Wash, a ridge of Palæozoic rocks exists at a greater or less depth, from or at the surface, on which little or usually no marine accumulations

could occur. Hence the coal-measures at Coalbrookdale, South Staffordshire, rest upon Silurian rock with a very little gannister grit (or none) intervening.

This ridge of old rocks, or 'central barrier,' was a Carboniferous land surface, and the grits collected on either flank, increasing however in thickness vastly far away to the north and west, and attaining a thickness of 9,000 feet in North Staffordshire, 12,130 feet in South Lancashire, and 18,700 feet in North Lancashire.

The thickness of the grits at the edge of the Staffordshire coal-field is only 200 feet, and it is 3,000 feet in Western Yorkshire.

The grits vary greatly in their lithology. Some are very rough and massive, others are fine-bedded micaceous sandstones and flags, whilst the bulk are jointed or are strata of varying thicknesses, and with the grains very visible to the eye. All are siliceous and felspathic, and the grains are often united by a felspathic matrix. The area whence the grits come, carried by marine currents, was in the north-west. Thin coal-seams and coal plants are found in some places in the grits, and sometimes a marine fauna exists, which contains fossils of the same species as those found in the lower strata called Carboniferous limestone.

The grits are divided into the Rough Rock, or first grit, which underlies the lower Coal-measures; the Flag Rock or Haslingdon Flags, or second grit, with shales and thin coal; the third grit of gritstone, flagstone shale, and thin coals, with marine fossils; the Kinderscout grit, or fourth grit: this forms the Peak in Derbyshire.

In Scotland the Moor rock, with thin seams of coal, is the equivalent of the English grits, and its very moderate thickness diminishes in Ayrshire, where it consists of a few beds of sandstone at the base of the coal-measures.

Carboniferous Limestone Series.—In Yorkshire there is a downward continuation of sandstones and shales, resembling those of the Millstone grits, with intercalated limestones, some of which are thick and crowded with *Encrinites*. Phillips called these the Yoredale series, and they attain the thickness of from 800 to 1,000 feet in Yoredale. The genera of marine fossils which are found in these strata are *Nautilus*, *Orthoceras*, *Phragmoceras*, *Goniatites*, *Euomphalus*, *Bellerophon*, *Cerithium*, *Spirifera*, *Phillipsia*, *Zaphrentis*, &c., and these are common in the underlying Carboniferous limestone. Beds of thin coals occur in the lower Yoredale strata. These strata are not found in the Centre and South of England, where the true Mountain or Carboniferous limestone exists.

This important limestone, well seen in Derbyshire, South Wales, and Somerset, is massive, well bedded and light-blueish, grey, reddish or black in colour, and it may be homogeneous or crystalline here and there. The limestones are thickest where the grits above, are thinnest, and have suffered much denudation where they are at the surface. The fossils contained are very numerous, and in some places *Encrinites* compose much of the rock, whilst Foraminifera are equally abundant elsewhere. The palæontology will be noticed further on. The base of this important set of strata varies much. In South Wales and Somersetshire, the base merges into a shale—Lower Limestone shale—and this into bottom beds of yellow and green sandstones and marls with plant remains, and a bone bed with *Placoid* fish remains. This rests on Old Red Sandstone. In some parts of Yorkshire, there are alternations of sands and clays at the base, with plant remains, and in the west of the county conglomerates form the base, and rest upon Silurian rocks, the Old Red Sandstone of the south-west not being present.

Elsewhere the base of the Limestone has either not been seen, or it rests on very old rocks without the intervention of a shale.

In central England, where the other sedimentary beds are reduced to about 3,000 feet, the Carboniferous Limestone attains an enormous thickness, and according to Mr. Hull's estimate, as much as 4,000 feet at Ashbourne, near Derby. To a certain extent, therefore, we may consider the calcareous member of the formation as having originated simultaneously with the accumulation of the materials of grit, sandstone, and shale, with seams of coal; just as strata composed of mud, sand, and pebbles, several thousand feet thick, with layers of vegetable matter, are now in the process of formation in the cypress swamps and delta of the Mississippi, while coral reefs are simultaneously forming on the coast of Florida, and in the sea of the Bermuda Islands. For we may safely conclude that in the ancient Carboniferous ocean those marine animals which secreted lime were never freely developed in areas where the rivers poured in fresh water charged with sand or clay; and the limestone could only become several thousand feet thick over parts of the ocean bed which was being slowly depressed, the water remaining perfectly clear for ages.

The Carboniferous Limestone, with its associated Yoredale series, diminishes in thickness northwards, and undergoes remarkable changes in its lithology and fossils in Scotland. Professor A. Geikie notices that the massive limestones dwindle down and are replaced by thick courses of yellow and white sandstone, dark shale, and seams of coal and ironstone. Lime-

stone beds are met with in thin sheets only. The whole formation is divided into the Carboniferous limestone and the underlying Calciferous sandstones. These last-mentioned strata are, at the bottom, red and yellow sandstones with many-coloured marls, which pass insensibly into the Old Red Sandstone beneath. They are very unfossiliferous, but *Sphenopteris affinis* is common. Above the red sandstones is the Cement stone group, of different coloured sandstones, shales, oil shales, and argillaceous limestones. In the West of Scotland these beds are poor in fossils. In the area of the Firth of Forth the Cement group contains ironstones, seams of coal, oil shales, and sandstones; and these last contribute to the building materials of Edinburgh. The oil shales yield petroleum on distillation.

Amongst the limestones of the group are the Burdie House limestones, composed of the tests of an Ostracod Crustacean, *Leperditia Okeni*, and containing fish, of which *Megalichthys* is a prominent form.

Seams of coal occur, and one called the Houston coal, is worked in Linlithgowshire. *Sphenopteris*, *Lepidostrobus*, *Araucarioxylon*, and *Lepidodendrons* are found, and *Pothocites* also.

The Carboniferous limestone group of Scotland probably represents the upper part of the English limestone in age, and consists of a few seams of Encrinital limestone, shales, fire-clays, and seams of coal. The thickest of the limestones, the Hurlet, is in places 100 feet thick; it overlies a seam of coal and pyritous shales, and above it are other important coal-seams and ironstones. These last contain marine fossils, and the coals have plants and fish remains and those of Labyrinthodontia. Some of the limestone seams are very persistent over great areas.

In Ireland the Carboniferous rocks of the North have their lower series like the Scottish calciferous sandstones. But in the southern districts there is a deep group of black and dark-grey shales, impure limestones, and grey and green grits with slates, which overlies the Old Red Sandstone, and is beneath the base of the Carboniferous limestone. This group is the Carboniferous slate. Its age is a question of dispute, and it may be either the equivalent of the Lower limestone shale of the South-west of England or be part of the Devonian formation. The Carboniferous limestone covers a large part of Ireland, and it splits up into sandstones towards the north.

Deposition of the Carboniferous formation.—It has been mentioned (p. 355) that Coal-measures rest upon Silurian and old rocks in some parts of the central barrier. This was the land of the age in the first instance. The sea breached in upon the Old Red Sandstone lake area, north of the Bristol Channel, and to

the north of the central barrier also, and the shales and sandstones of the lowest marine deposits accumulated. Further north there was a land vegetation, at times, during this age.

Sinking of the greater part of the area continued, probably along lines of fault, and a considerable depth of limestone was formed, and as time elapsed this became an arenaceous deposit in Yorkshire and northwards. Here and there were land surfaces, and coal-plants accumulated and formed coal. In Scotland the depression persisted, but silting up of the sea-floor and volcanic disturbance and ejections, enabled the terrestrial surfaces to be formed over and over again. Then came a long period of wear and tear of land, mostly situated in the north-west, and the age of the Millstone Grit set in. Even during its time there were a few land surfaces which produced coal. Subsequently the depression still continued and the deep Coal-measures accumulated.

The amount of volcanic energy displayed, was great at certain epochs of the Carboniferous age, and it will be noticed further on.

Enormous curving and dislocation of the Carboniferous rocks occurred, and great denudation of their exposed surfaces. Thousands of feet of coal-measures were worn off before the deposition of the Permian rocks and subsequently. It would appear that after the deposition of the Coal-measures, a thrust acted from north to south and south to north, forming great curvatures of the strata, the long axes being east and west. Denudation occurred, and the Permian deposits accumulated. Then curving occurred in the opposite direction, the axes of the curved strata being north and south. Hence more or less basin-shaped areas were produced; and denudation wore off and displayed the edges of the underlying grits and limestones on the edge of the basins.

The term Coal-field is applied to an area where coal is visible at the surface at its edges or outcrops, or where it is not too deeply seated to be worked. There are about 20 principal coal-fields in Great Britain, and several smaller ones. Some of these form complete basins, entirely circumscribed by the lower members of the formation, others have one part of the basin visible, the rest being covered up by Permian or other strata, and the rest are bounded by faults.

COAL-MEASURES.

Detailed Notice of the Sub-divisions.—A measure may be taken to be a coal-seam with its base of fire-clay and its roof of gravel or sandstone or shale.

Coal formed on land.—In South Wales, already alluded to, where the Coal-measures attain a great but variable thickness, the sandstones and shales throughout, appear to have been formed in water of moderate depth, during a slow, but perhaps intermittent, depression of the surface, in a region to which rivers were bringing a never-failing supply of muddy sediment and sand. The same area was alternately covered with vast forests, such as we see in the deltas of great rivers in warm climates, which are liable to be submerged beneath fresh or salt water, should the land sink vertically a few feet.

In one section near Swansea, in South Wales, where the total thickness of the Coal-measures is 3,246 feet, we learn from Sir H. de la Beche that there are ten principal masses of sandstone. One of these is 500 feet thick, and the whole of them make together a thickness of 2,125 feet. They are separated by masses of shale, varying in thickness from 10 to 50 feet. The intercalated coal-beds, sixteen in number, are generally from 1 to 5 feet thick, one of them, which has two or three layers of clay interposed, attaining 9 feet. At other points in the same coal-field the shales predominate over the sandstones. Great as is the diversity in the horizontal extent of individual coal-seams, they all present one characteristic feature, in having, each of them, what is called its *underclay*. These underclays, co-extensive with every layer of coal, consist of arenaceous shale, sometimes called fire-clay, because it can be made into bricks which stand a furnace heat. They vary in thickness from 6 inches to more than 10 feet, and, as Sir William Logan pointed out, are characterised by enclosing a peculiar fossil plant called *Stigmaria*. It was also observed that, while in the overlying shales or 'roof' of the coal, ferns and trunks of trees abound, without any *Stigmariæ*, and are flattened and compressed, those singular plants of the underclay most commonly retain their natural forms, unflattened and branching freely, sending out their slender rootlets in all directions. Several species of *Stigmaria* had long been known to botanists, and described by them, before their position under each seam of coal was pointed out, and before their true nature as the roots of trees (some having been actually found attached to the base of *Sigillaria* stumps) was recognised.

Now that all agree that these underclays are ancient soils, it follows that in every instance where we find them, they attest the terrestrial nature of the plants which formed the overlying coal, which consists of the trunks, branches, and leaves and spores of the plants which had their roots in the clay. The trunks have generally fallen prostrate in the coal, but some of

them still remain at right angles to the ancient soils (see fig. 432).

Professor Göppert, after examining the fossil plants of the coal-fields of Germany, has detected, in beds of pure coal, remains of every family of plants hitherto known to occur fossil in the Carboniferous rocks. Many seams, he remarks, are rich in *Sigillariæ*, *Lepidodendra*, and *Stigmariæ*, the latter in such abundance as to appear to form the bulk of the coal. In some places, almost all the plants were *Calamites*, in others ferns.[1]

Between the years 1837 and 1840, six fossil trees were discovered in the coal-field of Lancashire, where it is intersected by the Bolton Railway. They were all at right angles to the plane of the bed, which dips about 15° to the south. The distance between the first and the last was more than 100 feet, and the roots of all, were embedded in a soft argillaceous shale. In the same plane with the roots, is a bed of coal, 8 or 10 inches thick, which has been found to extend across the railway, or to the distance of at least ten yards. Just above the covering of the roots, yet beneath the coal-seam, so large a quantity of the *Lepidostrobus variabilis* was discovered enclosed in nodules of hard clay, that more than a bushel was collected from the small openings around the base of some of the trees. The exterior trunk of each was marked by a coating of friable coal, varying from one quarter to three-quarters of an inch in thickness; but it crumbled away on removing the matrix. The dimensions of one of the trees is 15½ feet in circumference at the base, 7½ feet at the top, its height being 11 feet. All the trees have large spreading roots, solid and strong, sometimes branching, and traced to a distance of several feet, and presumed to extend much farther.

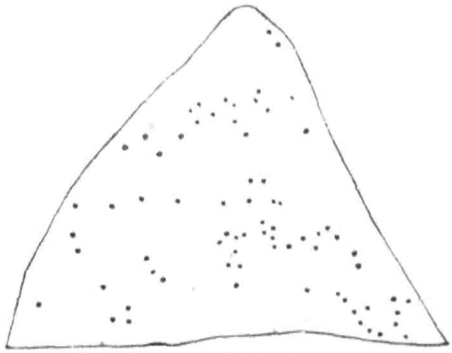
In a colliery near Newcastle a great number of *Sigillariæ* occur in the rock as if they had retained the position in which they grew. Not less than thirty, some of them 4 or 5 feet in diameter, were visible within an area of 50 yards square, the interior being sandstone, and the bark having been converted into coal.

It has been remarked that if, instead of working in the dark, the miner was accustomed to remove the upper covering of rock from each seam of coal, and to expose to the day the soils on which ancient forests grew, the evidence of their former method of growth would be obvious. Thus in South Staffordshire a seam of coal was laid bare in the year 1844, in what is called an open

[1] Quart. Journ. Geol. Soc. vol. v. Mem. p. 17.

work at Parkfield Colliery, near Wolverhampton. In the space of about a quarter of an acre the stumps of no less than seventy-three trees with their roots attached appeared, as shown in the

Fig. 430.



Ground plan of a fossil forest, Parkfield Colliery, near Wolverhampton, showing the position of 73 trees in a quarter of an acre.

annexed plan (fig. 430), some of them more than 8 feet in circumference. The trunks, broken off close to the root, were lying prostrate in every direction, often crossing each other. One of them measured 15, another 30 feet in length, and others less. They were invariably flattened to the thickness of one or two inches, and converted into coal. Their roots formed part of a stratum of coal 10 inches thick, which rested on a layer of clay 2 inches thick, below which was a second forest, resting on a 2-foot seam of coal. Again, five feet below this was a third forest with large stumps of *Lepidodendra*, *Calamites*, and other trees. In one instance of preserved trees, the direction of the prevailing wind of the age, was manifest from the bending of all the trunks in one direction.

Where coal occurs on Gannister—a gritty sandstone—there is no underclay, and usually marine remains are found above the seam. In this instance, the vegetation did not grow where it became mineralised, but was carried by water-power from some other locality and deposited.

The numerous coal-seams occurring one over the other, in a series of often 10,000 feet of vertical measurement, indicate that the plants grew on a rapidly subsiding area, into which the sea occasionally penetrated.

The depth of the Coal-measures is vast in Europe, but it can be best appreciated in the Bay of Fundy, in Nova Scotia,

for a natural section, ten miles in length, at South Joggins, in cliffs which I first examined in 1842, and afterwards with Dr. Dawson in 1845, has lately been admirably described by the last-mentioned geologist[2] in detail. And his evidence is most valuable as showing how large a portion of this dense mass was formed on land, or in swamps where terrestial vegetation flourished, or in freshwater lagoons. His computation of the thickness of the whole series of carboniferous strata as exceeding three miles, agrees with the measurement made independently by Sir William Logan in his survey of this coast.

Eighty-one seams of coal, varying in thickness from an inch to about five feet, have been discovered, and no less than seventy-one of them have been actually exposed in the sea-cliffs.

In the annexed section (fig. 431), which I examined in 1842,

Fig. 431.

Section of the cliffs of the South Joggins, near Minudie, Nova Scotia.

c. Grindstone. *d, g.* Alternations of sandstone, shale, and coal containing upright trees. *e, f.* Portion of cliff, given on a larger scale in fig. 432. *f.* 4-foot coal, main seam. *h, i.* Shale with freshwater Mussels.

the beds from *c* to *i* are seen all dipping the same way, their average inclination being at an angle of 24° S.S.W. The vertical height of the cliffs is from 150 to 200 feet; and between *d* and *g*—in which space I observed seventeen trees in an upright position, or, to speak more correctly, at right angles to the planes of stratification—I counted nineteen seams of coal, varying in thickness from 2 inches to 4 feet. At low tide, a fine horizontal section of the same beds is exposed to view on the beach, which at low tide extends sometimes 200 yards from the base of the cliff. The thickness of the beds alluded to, between *d* and *g*, is about 2,500 feet, the erect trees consisting chiefly of large *Sigillariæ*, occurring at ten distinct levels, one above the other. The usual height of the buried trees seen by me was from 6 to 8 feet; but one trunk was about 25 feet high and 4 feet in diameter, with a considerable bulge at the base. In no instance could I detect any trunk intersecting a layer of coal, however thin; and most of the trees terminated downwards in seams of coal. Some few only were based on clay and shale; none of them, except *Calamites*, on sandstone. The erect trees,

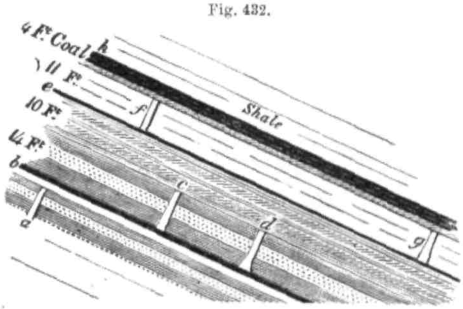
[2] Acadian Geology, 2nd edit. 1868.

therefore, appeared in general to have grown on beds of vegetable matter. In the underclays *Stigmaria* abounds.

These root-bearing beds have been found under all the coal-seams, and such old soils are at present the most destructible masses in the whole cliff, the sandstones and laminated shales being harder and more capable of resisting the action of the waves and the weather.

Dr. Dawson has enumerated more than 150 species of plants, two-thirds of which are European, a greater agreement than can be said to exist between the same Nova Scotia flora and that of the coal-fields of the United States. By referring to the section, fig. 431, the position of the four-foot coal will be perceived, and

Fig. 432.



Erect fossil trees, *a*, *c*, *d*, *f*, *g*. Coal-measures, Nova Scotia.

in fig. 432 (a section made by me in 1842 of a small portion) that from *e* to *f* of the same cliff is exhibited, in order to show the manner of occurrence of erect fossil trees, at right angles to the planes of the inclined strata.

In the sandstone, which filled the interior of the trees, I frequently observed fern-leaves, and sometimes fragments of *Stigmaria*, which had evidently entered together with sediment, after the trunk had decayed and become hollow, and while it was still standing under water. Thus the tree, *a*, fig. 432, represented in the bed *e* in the section, fig. 431, is a hollow trunk 5 feet 8 inches in length, traversing several strata, and cut off at the top by a layer of clay 2 feet thick, on which rests a seam of coal (*b*, fig. 432) 1 foot thick. On this coal again stood two large trees (*c* and *d*), while at a greater height the trees *f* and *g* rest upon a thin seam of coal (*e*), and above them is an underclay, supporting the 4-foot coal.

Occasionally the layers of matter in the inside of the tree are more numerous than those without; but it is more common in

for a natural section, ten miles in length, at South Joggins, in cliffs which I first examined in 1842, and afterwards with Dr. Dawson in 1845, has lately been admirably described by the last-mentioned geologist[2] in detail. And his evidence is most valuable as showing how large a portion of this dense mass was formed on land, or in swamps where terrestial vegetation flourished, or in freshwater lagoons. His computation of the thickness of the whole series of carboniferous strata as exceeding three miles, agrees with the measurement made independently by Sir William Logan in his survey of this coast.

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Section of the cliffs of the South Joggins, near Minudie, Nova Scotia.

c. Grindstone. *d, g.* Alternations of sandstone, shale, and coal containing upright trees. *e, f.* Portion of cliff, given on a larger scale in fig. 432. *f.* 4-foot coal, main seam. *h, i.* Shale with freshwater Mussels.

the beds from *c* to *i* are seen all dipping the same way, their average inclination being at an angle of 24° S.S.W. The vertical height of the cliffs is from 150 to 200 feet; and between *d* and *g*—in which space I observed seventeen trees in an upright position, or, to speak more correctly, at right angles to the planes of stratification—I counted nineteen seams of coal, varying in thickness from 2 inches to 4 feet. At low tide, a fine horizontal section of the same beds is exposed to view on the beach, which at low tide extends sometimes 200 yards from the base of the cliff. The thickness of the beds alluded to, between *d* and *g*, is about 2,500 feet, the erect trees consisting chiefly of large *Sigillariæ*, occurring at ten distinct levels, one above the other. The usual height of the buried trees seen by me was from 6 to 8 feet; but one trunk was about 25 feet high and 4 feet in diameter, with a considerable bulge at the base. In no instance could I detect any trunk intersecting a layer of coal, however thin; and most of the trees terminated downwards in seams of coal. Some few only were based on clay and shale; none of them, except *Calamites*, on sandstone. The erect trees,

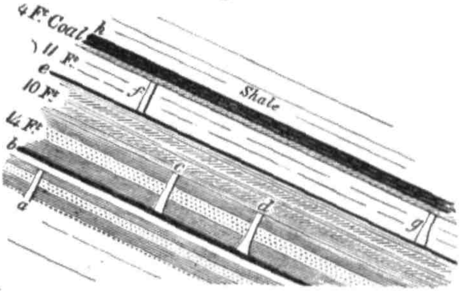
[2] Acadian Geology, 2nd edit. 1868.

therefore, appeared in general to have grown on beds of vegetable matter. In the underclays *Stigmaria* abounds.

These root-bearing beds have been found under all the coal-seams, and such old soils are at present the most destructible masses in the whole cliff, the sandstones and laminated shales being harder and more capable of resisting the action of the waves and the weather.

Dr. Dawson has enumerated more than 150 species of plants, two-thirds of which are European, a greater agreement than can be said to exist between the same Nova Scotia flora and that of the coal-fields of the United States. By referring to the section, fig. 431, the position of the four-foot coal will be perceived, and

Fig. 432.



Erect fossil trees, *a*, *c*, *d*, *f*, *g*. Coal-measures, Nova Scotia.

in fig. 432 (a section made by me in 1842 of a small portion) that from *e* to *f* of the same cliff is exhibited, in order to show the manner of occurrence of erect fossil trees, at right angles to the planes of the inclined strata.

In the sandstone, which filled the interior of the trees, I frequently observed fern-leaves, and sometimes fragments of *Stigmaria*, which had evidently entered together with sediment, after the trunk had decayed and become hollow, and while it was still standing under water. Thus the tree, *a*, fig. 432, represented in the bed *e* in the section, fig. 431, is a hollow trunk 5 feet 8 inches in length, traversing several strata, and cut off at the top by a layer of clay 2 feet thick, on which rests a seam of coal (*b*, fig. 432) 1 foot thick. On this coal again stood two large trees (*c* and *d*), while at a greater height the trees *f* and *g* rest upon a thin seam of coal (*e*), and above them is an underclay, supporting the 4-foot coal.

Occasionally the layers of matter in the inside of the tree are more numerous than those without; but it is more common in

the Coal-measures of all countries to find a cylinder of pure sandstone—the cast of the interior of a tree—intersecting a great many alternating beds of shale and sandstone, which originally enveloped the trunk as it stood erect in the water. Such a want of correspondence in the materials outside and inside, is just what we might expect if we reflect on the difference of time at which the deposition of sediment will take place in the two cases; the embedding of the tree having gone on for many years before its decay had made much progress. In many places distinct proof is seen that the enveloping strata took years to accumulate, for some of the sandstones surrounding erect sigillarian trunks, support at different levels roots and stems of *Calamites*; the *Calamites* having begun to grow after the older *Sigillariæ* had been partially buried. Still, the time could not have been very great.

One of the erect fossil trees of the South Joggins, 15 feet in height, occurring at a higher level than the main coal, has been shown by Dr. Dawson to have a coniferous structure, so that some *Coniferæ* of the Coal period grew in the same swamps as *Sigillariæ*, just as now the deciduous Cypress (*Taxodium distichum*) abounds in the marshes of Louisiana even to the edge of the sea.

When the carboniferous forests sank below high-water mark, a species of *Spirorbis* or *Serpula*, attached itself to the outside of the stumps and stems of the erect trees, adhering occasionally even to the interior of the bark—another proof that the process of envelopment was very gradual. These hollow upright trees, covered with innumerable marine annelids, reminded me of a 'cane-brake,' as it is commonly called, consisting of tall reeds, *Arundinaria macrosperma*, which I saw in 1846, at the Balize, or extremity of the delta of the Mississippi. Although these reeds are freshwater plants, they were covered with barnacles, having been killed by an incursion of salt water over an extent of many acres, where the sea had for a season usurped a space previously gained from it by the river. Yet the dead reeds, in spite of this change, remained standing in the soft mud, enabling us to conceive how easily the larger *Sigillariæ*, hollow as they were, but supported by strong roots, may have resisted an incursion of the sea.

The high tides of the Bay of Fundy, rising more than 60 feet, are so destructive as to undermine and sweep away continually the whole face of the cliffs, and thus a new crop of erect fossil trees is brought into view every three or four years. They are known to extend over a space between two or three miles from north to south, and more than twice that distance from east to

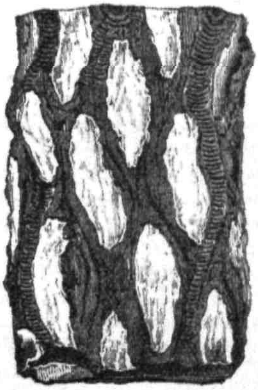
west, being seen in the banks of streams intersecting the coal-field.

Vegetation of the Coal period.—The Coal period was called by Adolphe Brongniart the age of Acrogens,[3] so great appears to have been the numerical preponderance of flowerless or cryptogamic plants of the families of ferns, club-mosses, and horse-tails. He stated that the state of the vegetable world was then extremely different from that now prevailing, not only because the cryptogamous plants constituted nearly the whole flora, but also because they were, on the whole, more highly developed than any belonging to the same class now existing, and contained some forms of structure now only found separately and in distinct orders of plants. The only phanerogamous plants which constitute any feature in the coal are the *Coniferæ*; Monocotyledons appear to have been very rare, and Angiospermous Dicotyledons, with one or two doubtful exceptions, are wanting. For this we are in some measure prepared by what we have seen of the Secondary or Mesozoic floras, if, consistently with

Fig. 433.

Pecopteris elliptica, Bunbury,[4] nat. size.

Fig. 434.



Caulopteris primæva, Lindley, ⅓.

the belief in the theory of evolution, we expect to find the prevalence of simpler and less specialised organisms in older rocks.

Ferns.—We are struck at the first glance, with the similarity of the ferns to those now living. In the fossil genus *Pecopteris*,

[3] For botanical nomenclature, see p. 173.
[4] Sir C. Bunbury, Quart. Journ. Geol. Soc. vol. ii. 1845.

for example (fig. 433), it is not easy to decide whether the fossils might not be referred to the same genera as those established for living ferns. The ferns of the Carboniferous period are generally found without organs of fructification, but in the few instances in which these do occur in a fit state for microscopical investigations, they agree with those of the living ferns.

When collecting fossil specimens from the coal-measures of Frostburg in Maryland, I found in the iron-shales several species with well-preserved rounded spots or marks of the sori. (See fig. 433.) In the general absence of such characters they have been divided into genera, distinguished chiefly by the branching of the fronds and the way in which the veins of the leaves are disposed. The larger portion are supposed to have been of the size of ordinary European ferns, but some were arborescent, especially those of the genus *Caulopteris* (fig. 434),

Fig. 436.

Fig. 437.

Fig. 435.

Living tree-ferns of different genera. (Ad. Brong.)

Fig. 435. Tree-fern from Isle of Bourbon.
Fig. 436. *Cyathea glauca*, Mauritius.
Fig. 437. Tree-fern from Brazil.

and of *Psaronius* of the upper coal-measures. *Caulopteris* resembled the modern *Alsophilæ*, and *Psaronius* the *Dicksoniæ*. The scars, or cicatrices, left after the fall of the fronds, resemble those of *Caulopteris*.

No less than 130 species of ferns are enumerated as having been obtained from the British coal-strata, and this number is

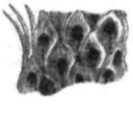
more than doubled if we include the Continental and American species. Even if we make some reduction on the ground of varieties which have been mistaken, in the absence of their fructification, for species, still the result is singular, because the whole of Europe affords at present no more than sixty-seven indigenous species.

Lycopodiaceæ.—*Lepidodendron.*—About forty species of fossil plants of the Coal have been referred to this genus, and more than one-half of them are found in the British Coal-measures. They consist of cylindrical stems or trunks, covered with leaf-scars. In their mode of branching they are always dichotomous (fig. 438). They belong to the *Lycopodiaceæ*, bearing sporangia and spores similar to those of the living representatives of this family (fig. 441); and although most of the Carboniferous species grew to the size of large trees, Mr. Carruthers has found by careful measurement, that the volume of the fossil spores did not exceed that of the recent club-moss. This is a fact of some geological importance, as it may help to explain the facility with which these spores may have been transported by the wind, causing that same wide distribution of the species of the fossil forests in Europe and America which we now observe in the

Fig. 438.

Fig. 439.

Fig. 440.



Lepidodendron Sternbergii. Coal-measures, near Newcastle.

Fig. 438. Branching trunk, 49 feet long, supposed to have belonged to *L. Sternbergii.* (Foss. Flo. 203.)

Fig. 439. Branching stem with bark and leaflets of *L. Sternbergii*, $\frac{1}{2}$. (Foss. Flo. 4.)

Fig. 440. Portion of same nearer the root. Natural size. (Ibid.)

geographical distribution of so many living families of cryptogamous plants. The figs. 438–440 represent a fossil *Lepidodendron*, 49 feet long, found in Jarrow Colliery, near Newcastle, lying in shale parallel to the planes of stratification.

Fragments of others, found in the same shale, indicate by the size of the rhomboidal scars which cover them, a still greater

Fig. 441.

a. Lycopodium densum. Living species. New Zealand.
b. Branch; natural size. *c.* Part of same, magnified.

magnitude. The living club-mosses, of which there are about 200 species, are most abundant in tropical climates. They usually creep on the ground, and are small, but some stand erect, as the *Lycopodium densum* from New Zealand (fig. 441), which attains a height of three feet.

Fig. 442.

a. Lepidostrobus ornatus, Brong. (Strobilus or cone), Shropshire; ½ nat. size.
b. Portion of a section showing the large sporangia in their natural position.
c. Microspores occurring in these sporangia, highly magnified.[5]

In the Carboniferous strata of Coalbrook Dale, and in many other coal-fields, elongated cylindrical bodies, called fossil cones, and named *Lepidostrobus* by M. Adolphe Brongniart, are met with (see fig. 442). They often form the nucleus of concretionary balls of clay-ironstone, and are well preserved, exhibiting a conical axis, around which a great quantity of scales were compactly imbricated. The opinion of M. Brongniart, that the *Lepidostrobus* is the fruit of *Lepidodendron*, has been confirmed, for these *strobili* or fruits have been found terminating the tips of branches of well-characterised *Lepidodendra* in Coalbrook Dale and elsewhere.

[5] Hooker, Mem. Geol. Survey, vol. ii. part 2, p. 440.

Equisetaceæ.—To this family belong two fossil genera of the coal, *Equisetites* and *Calamites*. The *Calamites* were evidently closely related to the modern Horse-tails genus (*Equisetum*), differing, however, in their great size, the want of sheaths at the joints,

Fig. 443.

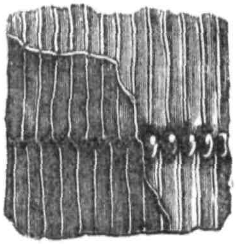
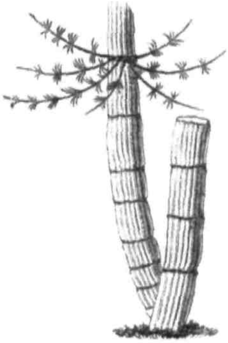


Fig. 443. *Calamites Sucowii*, Brong.; natural size.
Common in coal throughout Europe.

Fig. 444.



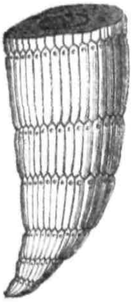
Stem of fig. 443, as restored by Dr. Dawson.

and some details of fructification, and especially in the more complex and highly organised structure of the woody zone, resembling in appearance the structure of exogenous plants. They grew in dense brakes on sandy and muddy flats, after the manner of modern Horse-tails, and their remains are common in the coal-measures. Seven species of this plant occur in the great Nova Scotia section before described, where the stems of some of them, five inches in diameter, and sometimes eight feet high, may be seen terminating downwards in a tapering root. Fig. 445 represents an inorganic cast of the internal cavity of a Calamite stem, the ridges and furrows being impressions of the inner surface of the woody zone. The little tubercles seen near the articulations, appear to be the scars of broken bundles of vessels.

Botanists are not yet agreed whether the *Asterophyllites* (see fig. 446) was the foliage of *Calamites* or not. Professor Williamson, from the microscopical examination of the internal structure of many well-preserved specimens, has come to the conclusion that the *Asterophyllites* did not belong even to the same natural order with the *Calamites*, but formed a distinct group, likewise cryptogamous, but more nearly related to the Lycopodiaceæ than to the Equisetaceæ. Dr. Dawson inclines to

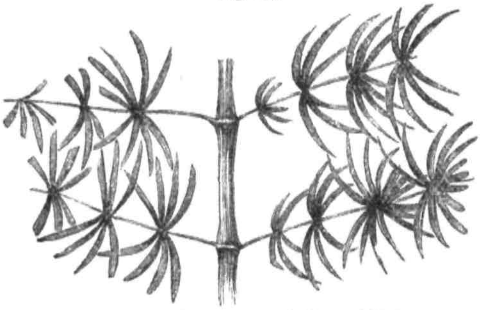
the same view from the presence of a mid-rib in the leaves of *Asterophyllites*, which is wanting in the leaves known to belong to some Calamites. Professor Schimper and Mr. Carruthers, however, consider that *Asterophyllites* is the foliage of *Cala-*

Fig. 445.



Radical termination of a Calamite. Nova Scotia.

Fig. 446.



Asterophyllites foliosus, Lindley and Hutton. Coal-measures, Newcastle.

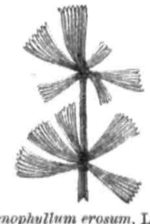
mites, and the latter even contends that he has found the leaves attached to a Calamite stem.

Figs. 447 and 448 represent leaves of *Annularia* and *Sphenophyllum*, common in the coal, and believed by Mr.

Fig. 447.

Annularia sphenophylloides, Zenker.

Fig. 448.



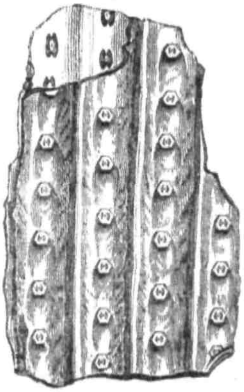
Sphenophyllum erosum, Lindley and Hutton.

Carruthers to be leaves of *Calamites*. There is still a difference of opinion as to whether these forms are, or are not, closely allied to *Asterophyllites*. Dr. Williamson, who has carefully studied the *Calamites*, thinks that they had a fistular pith, exogenous woody stem, and thick smooth bark, which last, having always disappeared, leaves a fluted stem as represented in fig. 443.

Sigillaria.—A large portion of the trees of the Carboniferous period belonged to this genus, of which as many as twenty-eight species are enumerated as British. The structure, both

internal and external, was very peculiar, and, with reference to existing types, very anomalous. They were formerly referred, by M. Ad. Brongniart, to ferns, which they resemble in the scalariform texture of their vessels, and in some degree in the form of the cicatrices left by the base of the leaf-stalks which have fallen off. (See fig. 449.) But some of them are ascertained to have had long linear leaves, quite unlike those of ferns. They grew to a great height, from 30 to 60, or even 70 feet, with regular cylindrical stems, and without branches, although some species were dichotomous towards the top. Their fluted trunks, from one to five feet in diameter, appear to have decayed more rapidly in the interior than externally, so that they became hollow when standing; and when thrown prostrate they were squeezed down and flattened.

Fig. 449.



Sigillaria lævigata, Brong.

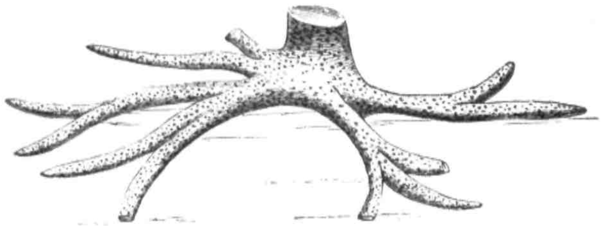
Hence, we find the bark of the two opposite sides (now converted into bright shining coal) constituting two horizontal layers, one upon the other, half an inch, or an inch, in their united thickness. These same trunks, when they are placed obliquely or vertically to the planes of stratification, retain their original rounded form, and are uncompressed, the cylinder of bark having been filled with sand, which now affords a cast of the interior.

Sir J. Hooker inclined to the belief that the *Sigillariæ* may have been cryptogamous, though more highly developed than any flowerless plants now living. Dr. Dawson having found in some species what he regards as medullary rays, thinks with Brongniart that they have some relation to gymnogens, while Mr. Carruthers leans to the opinion that they belong to the Lycopodiaceæ, amongst the Cryptogamia.

Stigmaria.—This fossil, the importance of which has already been pointed out (p. 359), was originally conjectured to be an aquatic plant. It is now ascertained to be the root of *Sigillaria.* The connection of the roots with the stem, previously suspected, on botanical grounds, by Brongniart, was first proved, by actual contact, in the Lancashire coal-field by Mr. Binney. This interesting connection was subsequently noticed, by Mr. Richard Brown, in his description of the *Stigmariæ* occurring in the under-

clays of the coal-seams of the island of Cape Breton, in Nova Scotia. In a specimen of one of these, represented in the annexed figure (fig. 450), the spread of the roots (*Stigmariæ*) was sixteen

Fig. 450.

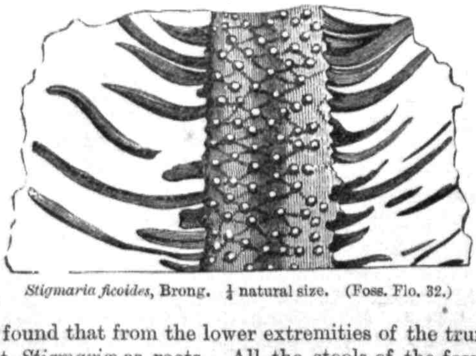


Stigmariæ attached to a trunk of *Sigillaria.*

feet, and some of them sent out rootlets, in all directions, into the surrounding clay. Mr. Richard Brown also found Stigmarian roots in the coal-field of Cape Breton attached to trees believed by him to be *Lepidodendra*, and Mr. Carruthers has confirmed this opinion from specimens of *Lepidodendron* occurring in British coal-fields. These facts are of great importance in helping to prove the affinity of *Sigillaria* and *Lepidodendron*, and thus confirming the opinion that the latter belong to the Lycopodiaceæ.

In the sea-cliffs of the South Joggins in Nova Scotia, I examined several erect *Sigillariæ*, in company with Dr. Dawson,

Fig. 451.

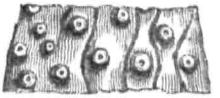


Stigmaria ficoides, Brong. ¼ natural size. (Foss. Flo. 32.)

and we found that from the lower extremities of the trunk they sent out *Stigmariæ* as roots. All the stools of the fossil trees dug out by us divided into four parts and these again bifurcated, forming eight roots, which were also dichotomous when

traceable far enough. The cylindrical rootlets formerly regarded as leaves are now shown by more perfect specimens, to have been attached to the root by fitting into deep cylindrical pits. In the fossil there is rarely any trace of the form of these cavities, in consequence of the shrinkage of the surrounding tissues. Where the rootlets are removed, nothing remains on the surface of the *Stigmaria* but rows of mammillated tubercles (figs. 451, 452), which have formed the base of each rootlet. These protuberances may possibly indicate the place of a joint at the lower extremity of the rootlet. Rows of these tubercles are arranged spirally round each root, and this always has a medullary axis and woody system much resembling that of *Sigillaria*, the structure of the vessels being, like it, scalariform. No instance seems yet to have been met with, in Nova Scotia, of Stigmarian roots attached to *Lepidodendron*.

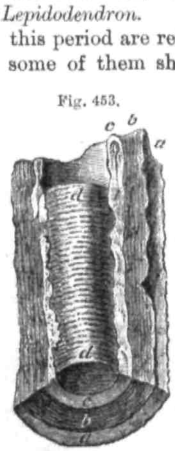
Fig. 452.



Surface of another individual of same species, showing form of tubercles. (Foss. Flo. 34.)

Coniferæ.—The coniferous trees of this period are referred to five genera; the woody structure of some of them showing that they were allied to the Araucarian division of Pines, more than to any of our common European Firs. Some of their trunks exceeded forty-four feet in height. Many, if not all of them, seem to have differed from living *Coniferæ* in having large piths; for Professor Williamson has demonstrated the fossil of the Coal-measures called *Sternbergia*, to be the pith of these trees, or rather the cast and cavities formed by the shrinking or partial absorption of the original medullary axis (see figs. 453, 454). This peculiar type of pith is observed in living plants of very different families, such as the common Walnut and the White Jasmine, in which the pith becomes so reduced as simply to form a thin lining of the medullary cavity, across which transverse plates of pith extend horizontally, so as to divide the cylindrical hollow into

Fig. 453.



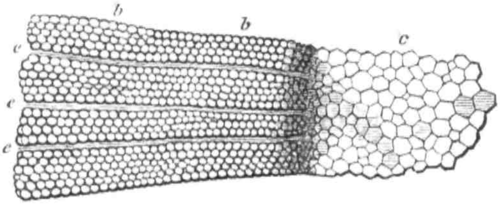
Fragment of coniferous wood, *Dadoxylon*, Endl., fractured longitudinally; from Coalbrook Dale. W. C. Williamson.[6]

a. Bark.
b. Woody zone or fibre (pleurenchyma).
c. Medulla or pith.
d. Cast of hollow pith or 'Sternbergia.'

[6] Manchester Phil. Mem. vol. ix. 1851.

discoid interspaces. When these interspaces have been filled up with inorganic matter, they constitute an axis to which, before their true nature was known, the provisional name of *Sternbergia* (*d*, *d*, fig. 453) was given. In the above specimen the structure of the wood (*b*, figs. 453 and 454) is coniferous, and the fossil is referable to the genus *Dadoxylon*.

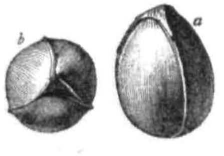
Fig. 454.



Magnified portion of fig. 453; transverse section.
c. Pith. *b*, *b*. Woody fibre. *e*, *e*. Medullary rays.

The fossil named *Trigonocarpon* (figs. 455 and 456), formerly supposed to be the fruit of a Palm, may now, according to Sir J. Hooker, be referred to the *Coniferæ*. Its geological import-

Fig. 455.



Trigonocarpon ovatum, Lindley and Hutton.
Peel Quarry, Lancashire.

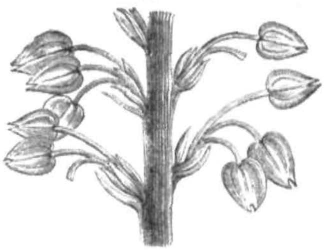
Fig. 456.

Trigonocarpon olivæforme, Lindley, with its fleshy envelope. Felling Colliery, Newcastle.

ance is great, for so abundant is it in the Coal-measures that in certain localities bushels of the fruit of some species may be procured; nor is there any part of the formation where it does not occur, except the underclays and limestone. The sandstone, ironstone, shales, and coal itself, all contain them. Mr. Binney has at length found in the clay-ironstone of Lancashire several specimens displaying structure, and from these, says Sir J. Hooker, we learn that the *Trigonocarpon*

belonged to that large section of existing coniferous plants which bear fleshy solitary fruits, and not cones. It resembled very closely the fruit of the Chinese genus *Salisburia*, one of the Yew order, or Taxaceæ of the class *Coniferæ*.

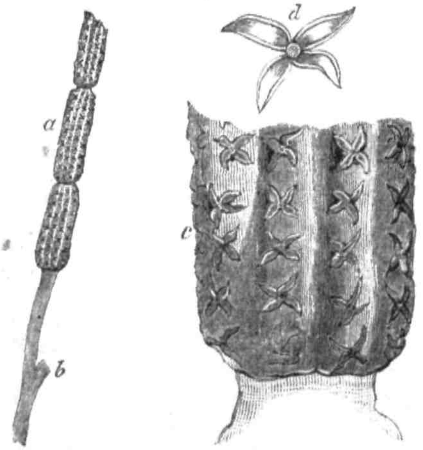
Fig. 457.



Cardiocarpon Lindleyi, Carr. (*Antholithes*, Lind.) Coal-measures, Falkirk.

The curious fossils called *Antholithes* by Lindley, which were formerly considered to be flower-spikes, are probably allied to the Coniferæ. No specimen has yet been found exhibiting structure, so that their true position is somewhat doubtful; but Mr. Peach in 1870 obtained specimens from carboniferous shales near Falkirk (see fig. 457), in which the fruit was attached to the stem, and Mr. Carruthers has ascertained that these fruits

Fig. 458.



Pothocites Grantonii, Pat. Coal-measures, Edinburgh.

a. Stem and spike; ½ nat. size. b. Remains of the spathe, magnified.
c. Portion of spike, magnified. d. One of the calyces, magnified.

are identical with others found in the coal-measures by Brongniart, and named by him *Cardiocarpon*. The processes supposed by Lindley to be petals prove to be pedicles of the fruit springing from each cluster of leaves on the axis. The fruit itself is

flat and broadly ovate, with a cordate base, and a somewhat acute bifid apex.[7]

Monocotyledon in the coal-measures.—In the coal-measures of Granton, near Edinburgh, a remarkable fossil (fig. 458) was found and described in 1840[8] by Dr. Robert Paterson. It was compressed between layers of bituminous shale, and consists of a stem bearing a cylindrical spike *a*, which in the portion preserved in the slate exhibits two subdivisions and part of a third. The spike is covered on the exposed surface with the four-cleft calyces of the flowers arranged in parallel rows. The stem shows at *b*, a little below the spike, remains of a lateral appendage, which is supposed to indicate the beginning of the spathe. The fossil has been referred to the *Aroideæ*, to which the recent genus Arum belongs. There can at least be no doubt as to the high grade of its organisation, and that it belongs to the monocotyledons. Mr. Carruthers has carefully examined the original specimen in the Botanical Museum, Edinburgh, and thinks it may have been an Epiphyte.

Climate of the Coal Period.—As to the climate of the Coal, the Ferns and the *Coniferæ* are perhaps the two classes of plants which may be most relied upon as leading us to safe conclusions, as the fossil genera are nearly allied to living types. All botanists admit that the abundance of ferns implies a moist atmosphere. But the *Coniferæ*, says Hooker, are of more doubtful import, as they are found in hot and dry and in cold and dry climates, in hot and moist and in cold and moist regions. In New Zealand the *Coniferæ* attain their maximum in numbers, constituting $\frac{1}{62}$ part of all the flowering plants; whereas in a wide district around the Cape of Good Hope they do not form $\frac{1}{1600}$ of the phanerogamic flora. Besides the *Coniferæ*, many species of ferns flourish in New Zealand, some of them aborescent, together with many kinds of *Lycopodium*; so that the vegetation of a forest in that country, may make a nearer approach to that of the Carboniferous age than any other now existing on the globe.

[7] Carruthers, Notes on Fossil Plants, Geol. Mag. vol. ix. 1872, p. 54.

[8] Trans. of Bot. Soc. Edinburgh, vol. i. 1844.

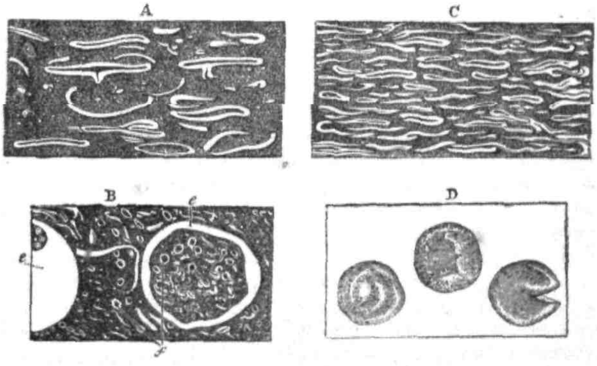
CHAPTER XXV.

CARBONIFEROUS FORMATION.

The structure of coal—Nature of coal—Formation of the mineral—Cause of purity—Clay-ironstone—Intercalated marine beds in coal-measures—Erroneous ideas about the atmosphere of the carboniferous age—Arthropode of coal—Insects—Spiders—Scorpions—Carboniferous amphibia—Labyrinthodontia — American and Nova Scotian amphibia—Pupa—Hylobius and Neuroptera—Crust movements in Nova Scotia—Marine fauna — Corals — Bryozoa — Crinoidea—Brachiopoda—Mollusca —Crustacea—Fish—Foraminifera.

Structure of Coal.—Professor Huxley has ascertained that in the Better-Bed coal of Lowmoor, near Leeds (see A B, fig. 459),

Fig. 459.



A. '*Better-Bed*' Coal, from a portion unusually full of *Sporangia*, which are here shown in transverse section.
B. Same coal, section parallel with bedding; showing *Sporangia*, *e*, and spores, *f*; the latter (which are here represented somewhat too large) appear as bright rings enclosing a dark spot.
C. Australian 'White Coal,' showing *Sporangia* in transverse section.
D. External view of *Sporangia* separated from the 'White Coal.'

All these figures are enlarged about 16 diameters.

The bodies here called *Sporangia* are by some persons considered to be *Macrospores*; and those called *Spores*, to be *Microspores*.

the spores and sporangia of the great plants of the Carboniferous age constitute a very large mass of the mineral, and this is also the case with the recent 'White Coal' of Australia

(c, fig. 459).[1] Professor Morris, in 1836, affirmed that these bodies were the spore-cases of a plant allied to the living Club-mosses, and Mr. Carruthers a few years ago confirmed this opinion by finding the discoidal sacs adhering to the leaves of the fossilized cone which produced them. He named the plant *Flemingites gracilis*, because Professor Fleming had previously pointed out similar bodies in the coal of Scotland. Professor Huxley is inclined to believe that the English coal is largely composed of these bodies, but Principal Dawson, who has made a careful examination of the 81 coal seams in Nova Scotia, both *in situ* and in specimens under the microscope, states that 'he could only recognise the bodies called by him Sporangites in sixteen seams, and of these only four had the rounded Lycopodiaceous spore-cases similar to those of *Flemingites*.' He maintains, therefore, that Sporangite beds are exceptional among coals, and that cortical and woody matters are the most abundant ingredients in all the ordinary kinds, and he does not think that the coals of England are likely to prove an exception.[2] The underclays are loamy soils, which must have been sufficiently above water to admit of drainage, and the absence of sulphurates, and the occurrence of carbonate of iron in them, prove that when they existed as soils, rain-water, and not sea-water, percolated them. With the exception, perhaps, of *Asterophyllites* (see fig. 446, p. 370), there is a remarkable absence from the Coal-measures, of any form of vegetation properly aquatic, the true coal being a sub-aërial accumulation in soil that was wet and swampy, but not permanently submerged.

The bituminous coal of Nova Scotia is similar in composition and structure to that of Great Britain, being chiefly derived from Sigillaroid trees mixed with leaves of ferns and of a Lycopodiaceous tree called *Cordaites* (*Noeggerathia*, &c.; for genus see fig. 429, p. 352), supposed by Dawson to have been deciduous, and which had broad parallel veined leaves without a mid-rib. On the surface of the seams of coal, are large quantities of mineral charcoal, which doubtless consist, as Dr. Dawson suggests, of fragments of wood which decayed in the open air, as would naturally be expected in swamps where so many erect trees were preserved. Beds of cannel-coal display, says Dr. Dawson, such a microscopical structure and chemical composition as shows them to have been of the nature of fine vegetable mud such as accumulates in the shallow ponds of modern swamps. It appears that in these cannel-coals the

[1] Huxley, Contemporary Review, 1870; and Critiques and Addresses, p. 92.

[2] Dawson, Spore-cases in Coal, Silliman's Journ. of Science, 1871, p. 261.

spore-cases of Lepidodendra are often more abundant than in the ordinary coal.

The nature of coal.—Coal is very amorphous, and only occasionally shows something of a fibrous structure, and it has a tendency to cleave in cubical or prismatic blocks. The divisional planes, often contain small films of calcite, gypsum, and iron pyrites and even salt. Light carburetted hydrogen or marsh-gas is often included, in considerable quantity, in coal.

Bituminous coals are those which soften or fuse when heated at a less temperature than that required for combustion ; there is nothing like bitumen in coal, however, and the proportion of carbon in such coals is from 80 to 90 per cent., and of hydrogen 4·5 to 6 per cent., and oxygen 3 to 14 per cent.

It appears from the researches of Liebig and other eminent chemists, that when wood and vegetable matter are buried in the earth exposed to moisture, and partially or entirely excluded from the air, they decompose slowly and evolve carbonic-acid gas, thus parting with a portion of their original oxygen. By this means they become gradually converted into lignite or wood-coal, which contains a larger proportion of hydrogen than wood does. A continuance of decomposition changes this lignite into common or bituminous coal, chiefly by the discharge of carburetted hydrogen, or the gas by which we illuminate our streets and houses. According to Bischoff, the inflammable gases which are always escaping from mineral coal, and are so often the cause of fatal accidents in mines, always contain carbonic acid, carburetted hydrogen, nitrogen, and olefiant gas. The disengagement of all these gradually transforms ordinary or bituminous coal into anthracite, to which the various names of glance-coal, coke, hard-coal, culm, and many others, have been given.

There is an intimate connection between the extent to which the coal has in different regions parted with its gaseous contents, and the amount of disturbance which the strata have undergone. The coincidence of these phenomena may be attributed partly to the greater facility afforded for the escape of volatile matter, when the fracturing of the rocks has produced an infinite number of cracks and crevices. The gases and water which were made to penetrate these cracks were probably rendered the more effective as metamorphic agents by increased temperature derived from the interior. It is well known that, at the present period, thermal waters and hot vapours burst out from the earth during earthquakes, and these would not fail to promote the disengagement of volatile matter from the carboniferous rocks if they occurred amongst them.

In Pennsylvania the strata of coal are horizontal to the westward of the Alleghany Mountains, where the late Professor H. D. Rogers pointed out that they were most bituminous; but as we travel south-eastward, where they no longer remain level and unbroken, the same seams become progressively debituminised in proportion as the rocks become more bent and distorted. At first on the Ohio river the proportion of hydrogen, oxygen, and other volatile matters, ranges from forty to fifty per cent. Eastward of this line, on the Monongahela, it still approaches forty per cent., where the strata begin to experience some gentle flexures. On entering the Alleghany Mountains, where the distinct anticlinal axes begin to show themselves, but before the dislocations are considerable, the volatile matter is generally in the proportion of eighteen or twenty per cent. At length, when we arrive at some insulated coal-fields associated with the boldest flexures of the Appalachian chain, where the strata have been actually turned over, as near Pottsville, we find the coal to contain only from six per cent. of volatile matter, thus becoming a genuine anthracite.

Cause of the purity of coal.—The purity of the coal itself, or the absence in it of earthy particles and sand, throughout areas of vast extent, is a fact which appears very difficult to explain when we attribute each coal-seam to a vegetation growing in swamps. It has been asked how, during river inundations capable of sweeping away the leaves of ferns and the stems and roots of *Sigillariæ* and other trees, could the waters fail to transport some fine mud into the swamps? One generation after another of tall trees grew with their roots in mud, and their leaves and prostrate trunks formed layers of vegetable matter, which was afterwards covered with mud since turned to shale. Yet the coal itself, or altered vegetable matter, remained all the while unsoiled by earthy particles. This enigma, however perplexing at first sight, may, I think, be solved by attending to what is now taking place in deltas. The dense growth of reeds and herbage which encompasses the margins of forest-covered swamps in the valley and delta of the Mississippi is such that the fluviatile waters, in passing through them, are filtered and made to clear themselves entirely before they reach the areas in which vegetable matter may accumulate for centuries, forming coal if the climate be favourable. There is no possibility of the least intermixture of earthy matter in such cases. Thus in the large submerged tract called the 'Sunk Country,' near New Madrid, forming part of the western side of the valley of the Mississippi, erect trees have been standing ever since the year 1811-12, killed by the great earthquake of

that date; lacustrine and swamp plants have been growing there in the shallows, and several rivers have annually inundated the whole space, and yet have been unable to carry in any sediment within the outer boundaries of the morass, so dense is the marginal belt of reeds and brushwood. It may be affirmed that generally in the 'cypress swamps' of the Mississippi no sediment mingles with the vegetable matter accumulated there from the decay of trees and semi-aquatic plants. As a singular proof of this fact, I may mention that whenever any part of a swamp in Louisiana is dried up, during an unusually hot season, and the wood set on fire, pits are burnt into the ground many feet deep, or as far down as the fire can descend, without meeting with water, and it is then found that scarcely any residuum or earthy matter is left. At the bottom of all these 'cypress swamps' a bed of clay is found, with roots of the tall cypress (*Taxodium distichum*), just as the underclays of the coal are filled with *Stigmaria*.

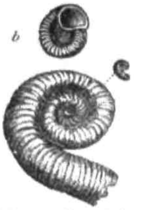
Clay-ironstone occurs as bands and nodules or in thin layers in the coal-measures, and they are formed, says Sir H. de la Beche, of carbonate of iron mingled mechanically with earthy matter, like that constituting the shales. The nodules have generally formed around some organic object, and in some instances, like the Mussel band ironstone, the valves of a shell of a mollusc have been converted into carbonate of iron. Mr. Robert Hunt found that decomposing vegetable matter, such as would be distributed through all coal strata, prevented the farther oxidation of the proto-salts of iron, and converted the peroxide into protoxide by taking a portion of its oxygen to form carbonic acid. Such carbonic acid, meeting with the protoxide of iron in solution, would unite with it and form a carbonate of iron; and this mingling with fine mud, when the excess of carbonic acid was removed, might form beds or nodules of argillaceous ironstone.[3]

Marine beds intercalated in coal-measures.—In the Coal-fields both of Europe and America the association of fresh, brackish-water, and marine strata with coal-seams of terrestrial origin is frequently recognised. Thus the upper member of the Coal-measures noticed in p. 354 was formed under brackish-water and marine conditions. The characteristic fossils are a small bivalve, having the form of a *Cyclas* or *Cyrena*, also a small Entomostracan, *Leperditia inflata* (fig. 461), and the small shell of a minute tubercular annelid of an extinct genus called *Microconchus* (fig. 460) allied to *Spirorbis*. In many coal-fields

[3] Memoirs of Geol Survey, vol. i. part i. pp. 51, 255, &c.

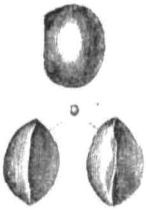
there are freshwater strata, some of which contain shells termed *Anthracosia* and *Anthracomya*, and referred to the family *Unionidæ*; but in the midst of the Coal series in Yorkshire there is

Fig. 460.



a. Microconchus (Spirorbis) carbonarius, Murch.
Nat. size and magnified.
b. Variety of same.

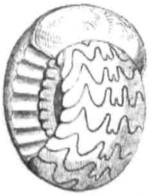
Fig. 461.



Leperditia inflata.
Nat. size and magnified.
Murchison.

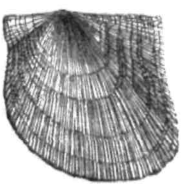
one thin but very widely spread stratum, abounding in fishes and marine shells, such as *Goniatites Listeri* (fig. 462), *Orthoceras*, and *Aviculopecten papyraceus*, Goldf. (fig. 463).

Fig. 462.



Goniatites Listeri, Martin, ⅔. Coal-measures, Yorkshire and Lancashire.

Fig. 463.



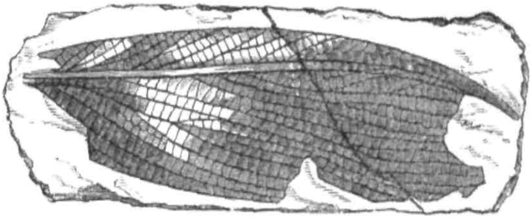
Aviculopecten papyraceus, Goldf., ½ (*Pecten papyraceus*, Sow.)

Arthropoda in the Coal-measures.—It was formerly believed that the atmosphere contained so much carbonic-acid gas during the Carboniferous age that no terrestrial animals could have lived. It was forgotten that marine andfreshwater animals breathe air through the medium of water, and that those of the past age, so closely resembled many forms now living, that there was an extreme probability of their existing under similar external conditions. The discovery of Insects, Spiders, Land shells, and Amphibia, set at rest what, at the best, was unworthy of credit.

The Insects of the period were numerous, and it will be noticed further on that their enemies were Spiders and Scorpions. The Beetles droned, and the Lace-winged flies flitted here and there, the Grasshoppers chirped, and the Leaf-insects preyed upon others.

Some of these insects did not undergo metamorphosis, but others must have done so. Coleoptera : The Beetles were of the genera *Curculioides* and *Troxites*. The Orthoptera, genera *Blattina*, *Gryllacris*, and *Acridites*, were the *Blattæ* and Crickets of the day. The genera *Lithomantis* and *Mantis* were the Leaf-insects. The Neuroptera had eight genera, including the White Ant, and it is probable that a *Tineina*, one of the scale-winged or Lepidoptera, lived then.

Fig. 464.



Wing of a Grasshopper, *Gryllacris lithanthraca*, Goldenberg, nat. size. Coal, Saarbrück, near Trèves.

The Arachnida existed in the forests of the Carboniferous formation, and Scorpions appear to have had a wide range, for they have been found in England, Scotland, Bohemia, and Illinois in the United States of North America. The forms resemble existing species somewhat, but should be included in the genus *Escorpius*. The genera *Microlabis* and *Cyclopthalmus* have also been found in Bohemia, and at Mazonia in Illinois. The False Scorpions of the genus *Architorbus* have been discovered fossil in Illinois and Lancashire, and *Eophrynus* at Coalbrook Dale and Dudley. Amongst the Spiders were the genera *Protolycosa* and *Arthrolycosa*.

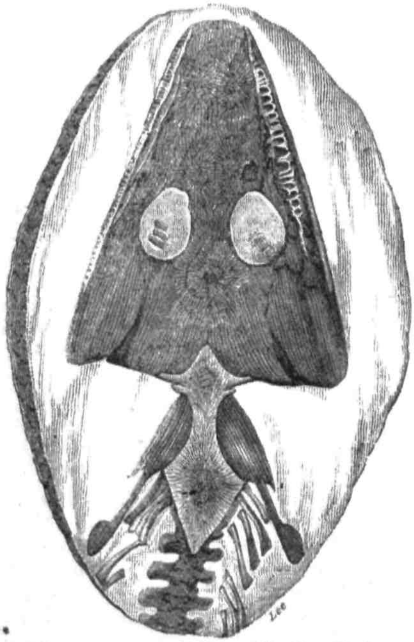
As will be noticed further on, the Hundred-legs or Myriapoda have been found fossil in Nova Scotia, and the same genus *Xylobius* had Scotch and English species. *Euphoberia* was very cosmopolitan, ranging from Central England to Illinois and Nova Scotia.

Carboniferous amphibia—Labyrinthodontia.—No vertebrated animals more highly organised than fishes were known to occur in rocks of higher antiquity than the Permian, until the year 1843, when the Amphibious *Apateon pedestris*, Meyer, was discovered in the coal-measures of Münster-Appel in Rhenish Bavaria.

Four years later, in 1847, Professor Von Dechen found remains of other species of Amphibia in the Saarbrück coal-

field. These were described by the late Professor Goldfuss under the generic name of *Archegosaurus*, but we owe our full and accurate knowledge of their structure to the investigations of Von Meyer. The annexed drawing shows the skull, thoracic plate, scapulæ, vertebræ, and ribs of *Archegosaurus minor*. Among the more remarkable features of *Archegosaurus* are, firstly, the complete protection of the upper surface of the skull by bony plates, which fit accurately together at all stages of growth ; secondly the thoracic shield, consisting of three bony plates, of which the two outer overlap the central one ; thirdly the ventral armour, composed of numerous imbricated bony scutes (fig. 466) disposed diagonally upon the under surface, between the fore and hind limbs. Fourthly, the teeth somewhat resemble those of *Mastodonsaurus* (fig. 394), but the folding of the dentinal wall is less complex. Fifthly, *Archegosaurus* retained throughout life, imperfectly ossified or notochordal vertebræ. The total length of a large individual may have been about seven feet.

Fig. 465.



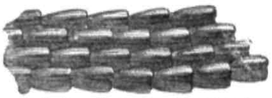
Archegosaurus minor, Goldfuss. Fossil reptile from the coal-measures, Saarbrück.

Since the first discovery of Carboniferous Labyrinthodonts in Germany, many additional genera and species have been brought to light. According to Professor Miall, at least thirteen genera have been found in the British Isles, particularly in the coal-fields of Edinburgh, Glasgow, Northumberland, Kilkenny, and Staffordshire. One example has been discovered in the Yoredale Rocks of North Yorkshire. They were predaceous

freshwater creatures, and ranged in size from a few inches to eight feet.

Labyrinthodont footprints in American coal-measures.—In 1844, the very year in which the *Apateon* was discovered, Dr. King published an account of the footprints of a large Amphibian, *Sauropus*, found by him in the Coal-strata of Greensburg, in Westmoreland County, Pennsylvania; and I had an opportunity of examining them when in that country in 1846. The footmarks were first observed standing out in relief from the lower surface of slabs of sandstone, resting on thin layers of fine unctuous clay. I brought away one of these masses, which is represented in the accompanying drawing (fig. 467). It displays, together with footprints, the casts of cracks (a, a') of various sizes. The origin of such cracks in clay, and casts of the same, has before been explained, and referred to the drying and shrinking of mud, and the subsequent pouring of sand into open crevices. It will be seen that some of the cracks, as at b, c, traverse the footprints, and produce distortion in them, as might have been expected, for the mud must have been soft when the animal walked over it and left the impressions; whereas, when it afterwards dried up and shrank, it would be too hard to receive such indentations.

Fig. 466.



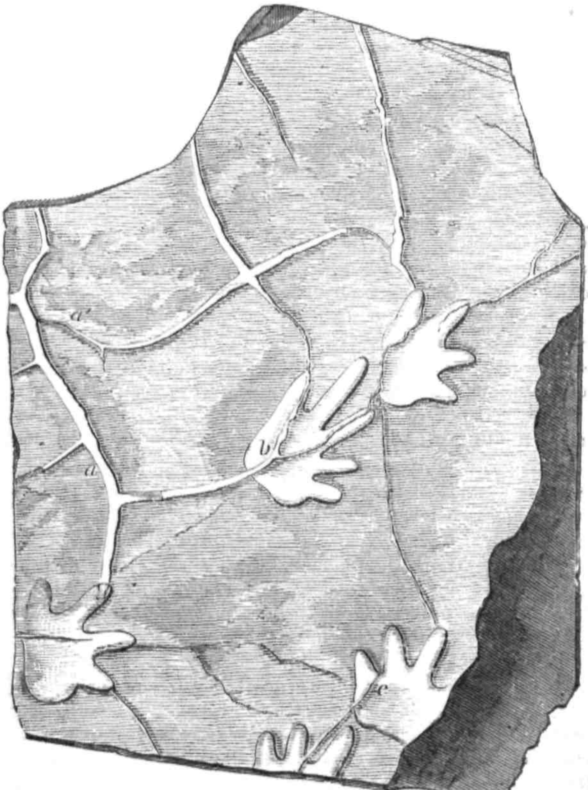
Imbricated covering of skin of *Archegosaurus medius*, Goldf. Magnified.

We may assume that the animal which left these prints on the ancient sands of the Coal-measures, was an air-breather, because its weight would not have been sufficient under water to have made impressions so deep and distinct. The same conclusion is also borne out by the casts of the cracks above described, for they show that the clay has been exposed to the air and sun, so as to have dried and shrunk.

Discoveries of Terrestrial Animals in Nova Scotia.—If we have rightly interpreted the evidence of the former existence, at more than eighty different levels, of forests, some of them of vast extent, and which lasted for ages, giving rise to a great accumulation of vegetable matter, it is natural to ask whether there were not many air-breathing inhabitants of these same regions. As yet no remains of mammalia or birds have been found, a negative character common at present to all the Palæozoic formations, but in 1852 the osseous remains of an Amphibian, the first ever met with in the Carboniferous strata of the American continent, were found by Dr. Dawson and myself. We detected them in the interior of one of the erect *Sigillariæ* before alluded to as of such frequent occurrence in

Nova Scotia. The tree was about two feet in diameter, and consisted of an external cylinder of bark, converted into coal, and an internal stony axis of black sandstone, or rather mud and

Fig. 467.



Scale one-sixth the original.

Slab of sandstone from the Coal-measures of Pennsylvania, with footprints of air-breathing amphibian and casts of cracks.

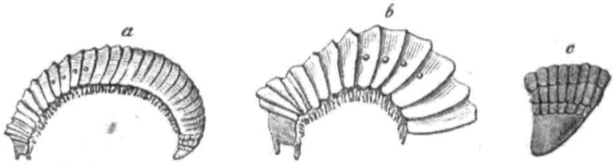
sand stained black by carbonaceous matter, and cemented together with fragments of wood into a rock. These fragments were in the state of charcoal, and seem to have fallen to the bottom of the hollow tree while it was rotting away. The skull, jaws, and vertebræ of an Amphibian, probably about $2\frac{1}{2}$ feet

in length (*Dendrerpeton Acadianum*, Owen), were scattered through this stony matrix. The shell, also, of a *Pupa* (fig. 469, p. 388), the first land-shell ever met with in the coal, or in beds older than the tertiary, was observed in the same stony mass. Dr. Wyman of Boston pronounced the reptile to be allied in structure to *Monobranchus* and *Menopoma*, species of Amphibia now inhabiting the North American rivers. The same view was afterwards confirmed by Professor Owen, who also pointed out the resemblance of the cranial plates to those seen in the skull of *Archegosaurus* and *Labyrinthodon*.[4] Whether the creature had crept into the hollow tree while its top was still open to the air, or whether it was washed in with mud during a flood, or in whatever other manner it entered, must be a matter of conjecture.

The remains of a second and smaller species of *Dendrerpeton*, *D. Oweni*, were also found accompanying the larger one, and still retaining some of its dermal appendages; and in the same tree were the bones of a third small Amphibian, *Hylonomus Lyelli*, 7 inches long, with stout hind limbs, and fore limbs comparatively slender, supposed by Dr. Dawson to be capable of walking and running on land.[5]

In a second specimen of an erect stump of a hollow tree 15 inches in diameter, the ribbed bark of which showed that it was

Fig. 468.



Xylobius Sigillariæ, Dawson. Coal, Nova Scotia and Great Britain.
a. Natural size. *b*. Anterior part, magnified. *c*. Caudal extremity, magnified.

a *Sigillaria*, and which belonged to the same forest as the specimen examined by us in 1852, Dr. Dawson obtained not only fifty specimens of *Pupa vetusta* (fig. 469), and nine skeletons of Labyrinthodontia, belonging to four species, but also several examples of an articulated animal resembling the recent Centipede or galley worm, a creature which feeds on decayed vegetable matter (see fig. 468). Under the microscope, the head, with the eyes, mandible, and labrum are well seen. It is interesting, as being the earliest known representative of the Myriapoda, none

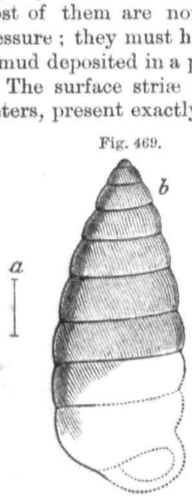
4 Quart. Journ. Geol. Soc. vol. ix. p. 58.
5 Dawson, Air-Breathers of the Coal in Nova Scotia. Montreal, 1863.

of which had previously been met with in rocks older than the Oolite or Lithographic slate of Germany.

Some years afterwards, Dr. Dawson, in carefully examining the same great section, containing so many buried forests in the cliffs of Nova Scotia, discovered another fossiliferous bed, separated from the tree containing *Dendrerpeton* by a mass of strata more than 1,200 feet thick. As there were 21 seams of coal in this intervening mass, the length of time comprised in the interval is not to be measured by the mere thickness of the sandstones and shales. This lower bed is an under-clay seven feet thick, with Stigmarian rootlets, and the small land-shells occurring in it are in all stages of growth. They are chiefly confined to a layer about two inches thick, and are unmixed with any aquatic shells. They were entire when embedded, but most of them are now crushed, flattened, and distorted by pressure; they must have been accumulated, says Dr. Dawson, in mud deposited in a pond or creek.

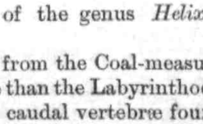
The surface striæ of *Pupa vetusta*, when magnified 50 diameters, present exactly the same appearance as a portion corresponding in size of the common English *Pupa juniperi*, and the internal hexagonal cells, magnified 500 diameters, show the internal structure of the fossil and recent form to be identical. In 1866 [6] Dr. Dawson discovered in this lower bed, so full

Fig. 469.



Pupa vetusta, Dawson.
a. Natural size.

Fig. 470.



Zonites (*Conulus*) *priscus*, Carpenter.
b. Magnified.

of *Pupa vetusta*, another land-shell of the genus *Helix* (subgenus *Zonites* or *Conulus*) (fig. 470).

None of the Vertebrata obtained from the Coal-measures of the South Joggins are of a higher grade than the Labyrinthodonts, but some were of very great size, two caudal vertebræ found by Mr. Marsh in 1862 measuring two and a-half inches in diameter, and implying a gigantic Amphibian with a powerful swimming tail.

[6] Dawson, Acadian Geology, 1868, p. 385.

Except some obscure traces of an Insect found by Dr. Dawson, in a coprolite of some Amphibian, occurring in a fossil tree, no specimen of this class has been brought to light in the Joggins. But Mr. James Barnes found in a bed of shale at Little Glace Bay, Cape Breton, the wing of an *Ephemera*, which must have measured 7 inches from tip to tip of the expanded wings, larger than any known living insect of the Neuropterous family.

Carboniferous rain-prints.—At various levels in the coal-measures of Nova Scotia ripple-marked sandstones, and shales with rain-prints, were seen by Dr. Dawson and myself, but still more perfect impressions of rain were discovered by Mr. Brown near Sydney in the adjoining island of Cape Breton. They consist of very delicate markings on greenish slates,

Fig. 471. Fig. 472.

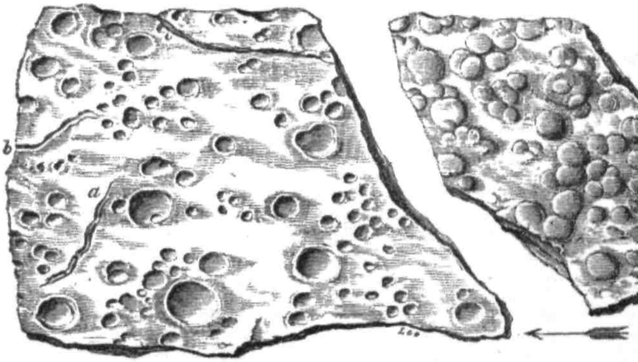


Fig. 471. Carboniferous rain-prints with worm-tracks (*a*, *b*) on green shale, from Cape Breton, Nova Scotia. Natural size.
Fig. 472. Casts of rain-prints on a portion of the same slab (fig. 471), seen to project on the under side of an incumbent layer of arenaceous shale. Natural size.
The arrow represents the supposed direction of the shower.

accompanied by worm-tracks (*a*, *b*, figs. 471, 472) such as are often seen between high and low water-mark on the recent mud of the Bay of Fundy.

The great humidity of the climate of the Coal period had been previously inferred from the number of its ferns and the continuity of its forests for hundreds of miles; but it is satisfactory to have at length obtained such positive proofs of showers of rain, the drops of which resembled in their average size those which now fall from the clouds. From such data we may presume that the atmosphere of the Carboniferous period

corresponded in density with that now investing the globe, and that different currents of air varied then as now in temperature, so as to give rise, by their mixture, to the condensation of aqueous vapour.

Folding and denudation of the beds indicated by the Nova Scotia coal-strata.—The series of events which are indicated by the great section of the coal-strata in Nova Scotia consist of a gradual and long-continued subsidence of a tract of land which was constantly in the state of a delta, though occasionally submerged beneath a sea of moderate depth. Deposits of mud and sand were first carried down into a shallow sea, on the low shores of which the foot-prints of reptiles were sometimes impressed. Though no regular seams of coal were then formed, the embedded coal-plants are of the characteristic genera *Cyclopteris* and *Alethopteris*, agreeing with species occurring at much higher levels, and distinct from those of the antecedent Devonian group. The *Lepidodendron corrugatum* (see fig. 473), a plant predominating in the Lower Carboniferous group of Europe, is also conspicuous in these shallow-water beds, together with many fishes and Entomostraca. A more rapid rate of subsidence sometimes converted part of the sea into deep clear water, in which there was a growth of coral which was afterwards turned into crystalline limestone and gypsum. In spite of continued sinking, amounting to several

Fig. 473.

Cone and branch of *Lepidodendron corrugatum*. Lower Carboniferous, New Brunswick.

Fig. 474.

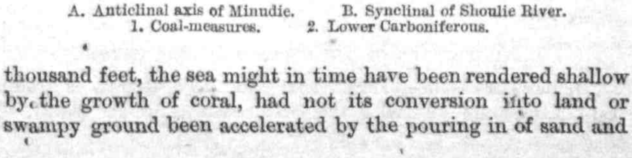


Diagram showing the curvature and supposed denudation of the Carboniferous strata in Nova Scotia.

A. Anticlinal axis of Minudie. B. Synclinal of Shoulie River.
1. Coal-measures. 2. Lower Carboniferous.

thousand feet, the sea might in time have been rendered shallow by the growth of coral, had not its conversion into land or swampy ground been accelerated by the pouring in of sand and

the advance of the delta accompanied with such fluviatile and brackish-water formations as are common in lagoons.

The amount of sinking of the bed of the sea which took place in order to allow of the formation of so vast a thickness of rock of sedimentary and organic origin, is expressed by the total thickness of the Carboniferous strata, including the coal-measures, No. 1, and the rocks which underlie them, No. 2, fig. 474.

After the strata No. 2 had collected, the conditions proper to a great delta exclusively prevailed, the subsidence still continuing so that one forest after another grew and was submerged until their under-clays with roots, and usually seams of coal, were left at more than eighty distinct levels. Here and there also deposits bearing testimony to the existence of fresh or brackish-water lagoons, filled with calcareo-bituminous mud, were formed. In these beds (*h* and *i*, fig. 431) are found freshwater bivalves or Mussels allied to *Anodon*, though not identical with that or any living genus, and called *Naiadites carbonarius* by Dawson. They are associated with small Entomostracous Crustacea of the genus *Cythere*, and scales of small fishes. Occasionally some of the Calamite brakes and forests of Sigillariæ and Coniferæ were exposed in the flood season, or sometimes, perhaps by slight elevatory movements, to the denuding action of the river or the sea.

In order to interpret the great coast section exposed to view on the shores of the Bay of Fundy (fig. 474), the student must in the first place understand that there have been two great movements in opposite directions, the first consisting of a general sinking of three miles, which took place during the Carboniferous period, and the second a side to side crush, and an upheaval of more limited horizontal extent, during which the anticlinal and synclinal axes A, B, were formed. That the first great change of level was one of subsidence is proved by the fact that there are shallow-water deposits at the base of the Carboniferous series, or in the lowest beds of No. 2.

The rocks subsequently removed by denudation are expressed by the faint lines at A; and thus the student will see that, according to the principles laid down in the seventh chapter, we are enabled, by the joint operations of upheaval and denudation, to look, as it were, about three miles into the interior of the earth without passing beyond the limits of a single formation.

MARINE FAUNA OF THE CARBONIFEROUS PERIOD.

It has already been stated that the Carboniferous or Mountain Limestone underlies the coal-measures in the South of

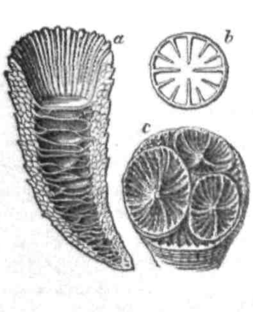
England and Wales, whereas in the North and in Scotland marine calcareous rocks partly of the age of the Mountain Limestone alternate with shales and sandstones, containing seams of coal. In its most calcareous form the Mountain Limestone is destitute of land-plants, and is loaded with marine remains—the greater part, indeed, of the rock being made up bodily of Crinoids, Corals, and Bryozoa with Mollusca and Foraminifera interspersed.

Corals.—The corals deserve especial notice, as the cup-and-star corals, which have the most massive and stony skeletons, display peculiarities of structure by which they may be distinguished generally, as MM. Milne-Edwards and Haime first pointed out, from all species found in strata newer than the Permian. There is, in short, an ancient or *Palæozoic*, and a modern or *Neozoic* type, if by the latter term we designate (as proposed by Professor E. Forbes) all strata from the triassic to the most modern, inclusive. The accompanying diagrams (figs. 475, 476) illustrate these types.

It will be seen that the more ancient corals have what is called a quadripartite arrangement of the chief vertical plates or *lamellæ* (septa)—parts of the skeleton which support the organs of reproduction. The number of these lamellæ in the Palæozoic type is 4, 8, 16, &c.; while in the Neozoic type the number is 6, 12, 24, or some other multiple of six; and this holds good,

Fig. 475.

Palæozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA RUGOSA, Milne-Edwards and Jules Haime.



a. Vertical section of *Cyathophyllum flexuosum*, Goldfuss; ½ nat. size; from the Devonian of the Eifel. The septa are seen around the inside of the cup; the walls consist of cellular tissue; and large transverse plates, called *tabulæ*, divide the interior into chambers.

b. Arrangement of the septa in *Polycœlia profunda*, Germar, sp.; nat. size; from the Magnesian Limestone, Durham. This diagram shows the quadripartite arrangement of the primary septa, characteristic of palæozoic corals, there being 4 principal and 8 intermediate lamellæ, the whole number in this type being always a multiple of four.

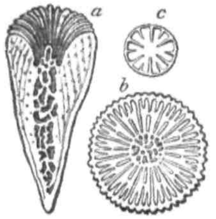
c. Stauria astræiformis, Milne-Edwards. Young group, nat. size. Upper Silurian, Gothland. The lamellæ or septa in each cup are divided by four prominent ridges into four groups.

whether they be simple forms, as in fig. 475, *a*, and 476, *a*, or aggregate clusters of corallites, as in 475, *c*. But further investigations have shown in this, as in all similar grand generalisations in natural history, that there are exceptions to the rule.

Thus in the Lower Greensand *Holocystis elegans* (Lonsdale, sp.) and other forms have some relics of the Palæozoic type, and

Fig. 476.

Neozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA APOROSA, M. Edwards and J. Haime.



a. Parasmilia centralis, Mantell, sp. Vertical section; nat. size. Upper Chalk, Gravesend. In this type the *lamellæ* extend to the columella composed of loose cellular tissue, and there are no *tabulæ*.

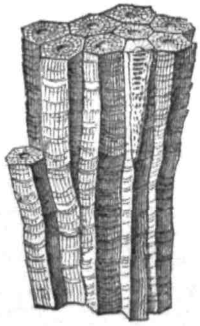
b. Caryophyllia Bowerbankii, Ed. and H. Transverse section, enlarged. Gault, Folkestone. In this coral the primary septa are a multiple of six. The six primary and six secondary septa reach the columella, and between each pair of long septa there is a tertiary septum with a quaternary on either side, in all forty-eight. The short intermediate plates which proceed from the columella are called *pali*.

c. Fungia patellaris, Lamk. Recent; very young state. Diagram of its six primary and six secondary septa, magnified.

Dr. Duncan has shown to what small extent the Neozoic forms penetrate downwards into the Carboniferous and Devonian rocks.

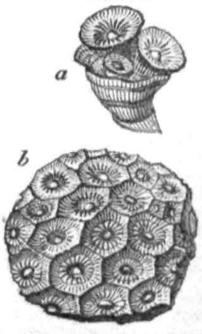
From a great number of rugose corals met with in the Mountain Limestone, two species (fig. 477, 478) have been selected, as having

Fig. 477.



Lithostrotion basaltiforme, Phil. sp. ½. England; Ireland; Russia; Iowa, and westward of the Mississippi, United States.

Fig. 478.



Lonsdaleia floriformis (Martin, sp.), ½. *a.* Young specimen, with buds or corallites on the disk, illustrating calicular gemmation. *b.* Part of a full-grown compound mass.

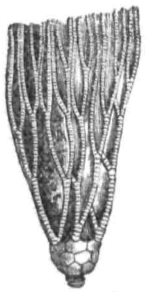
a very wide range, extending from the eastern borders of Russia to the British Isles and United States. These fossils, together with numerous species of *Zaphrentis*, *Amplexus*, *Cyathophyllum*, and *Clisiophyllum*, form a group of rugose corals widely different

from any that followed them. With them are associated certain tabulate corals, especially *Michelinia* and *Syringopora*, the latter of which often formed small reefs.[7]

Echinodermata.—*Crinoidea* are numerous in the Mountain Limestone.

In the greater part of them, the cup or pelvis (fig. 480*b*) is often greatly developed in size in proportion to the arms, although this is not the case in *Cyathocrinus*. The genera *Poteriocrinus*, *Cyathocrinus*, *Actinocrinus*, and *Platycrinus*, are all of them characteristic of this formation, and their separated plates and the joints of their stems compose rocks many hundred feet in thickness (*Crinoidal limestones*). Other Echinoderms are rare, a few

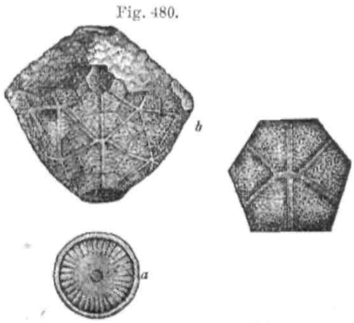
Fig. 479.



Cyathocrinus planus, Miller.

Body and arms.
Mountain Limestone.

Fig. 480.



Cyathocrinus caryocrinoides, M'Coy.

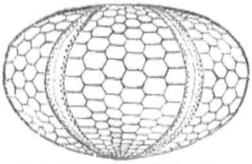
a. Surface of one of the joints of the stem.
b. Pelvis or body; called also calyx or cup.
c. One of the pelvic plates.

Echinoidea only being known; these have a complex structure, with many more interambulacral plates than are seen in the modern genera of the same group. One genus, *Palæchinus* (fig. 481), lived like the modern *Echinus*, but has four, five, or six rows of plates in the interambulacral region, whereas the modern genera have only two. The other, *Archæocidaris*, represents, in like manner, the *Cidaris* of the present seas. The Blastoidea replaced, in the Carboniferous, the Cystidea of the Silurian seas; two genera, *Pentremites* and *Codonaster*, are peculiar to this formation in Europe and North America. *Pentremites* (fig. 482) is much the most abundant genus, and, like *Codonaster*, is distinguished from the true Crinoids and Cystoidea by the absence of arms.

7 For figures of these corals, see Palæontographical Society's Monographs, 1852.

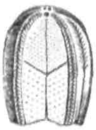
Molluscoida.—The Bryozoa are very common in some parts of the Mountain Limestone of England, and in the Calciferous deposits of Scotland, the prevailing genera being *Fenestella*,

Fig. 481.



Palæchinus gigas, M'Coy, ⅓. Reduced one-third. Carboniferous Limestone. Ireland.

Fig. 482.

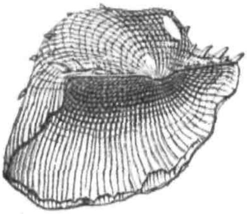


Pentremites ellipticus, Sow., ⅔. Carb. Limestone, Derbyshire, &c.

Vincularia, *Polypora*, *Diastopora*, and *Glauconeme*. Their net-like fronds are easily recognised.

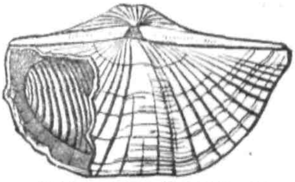
The Brachiopoda are very important in the fauna, but they

Fig. 483.



Productus semireticulatus, Martin, sp., ½. (*P. antiquatus*, Sow.) Carboniferous Limestone. England; Russia; the Andes, &c.

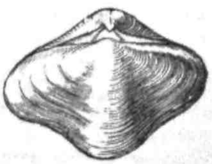
Fig. 484.



Spirifera trigonalis, Martin, sp., nat. size. Carboniferous Limestone. Derbyshire, &c.

did not preponderate over the Mollusca proper, as was the case in the previous or earlier formations. The commonest genera are *Productus*, *Spirifera*, *Rhynchonella*, and *Athyris*, and the most characteristic shells of the formation are those of *Productus giganteus*, *P. semireticulatus* (fig. 483), and *P. scabriculus*. Large plaited *Spirifera*, as *Spirifera striata*, *S. rotundata*, and *S. trigonalis* (fig. 484), also abound; and smooth species, such as *Spirifera glabra* (fig. 485), with its numerous varieties.

Fig. 485.



Spirifera glabra, Martin, sp. ⅓. Carboniferous Limestone.

Terebratula hastata (fig. 486) deserves mention, not only for its wide range, but because it often retains the pattern of the original coloured stripes which ornamented the living shell.

Mollusca.—The Lamellibranchs number 334 species in the English Carboniferous Limestone. The genera *Aviculopecten* (fig. 487) has a species in which dark stripes alternate with a light ground.

Some few of the Carboniferous mollusca, such as *Avicula*,

Fig. 486.

Terebratula hastata, Sow., $\frac{2}{3}$, with radiating bands of colour. Carboniferous Limestone. Derbyshire; Ireland; Russia, &c.

Fig. 487.

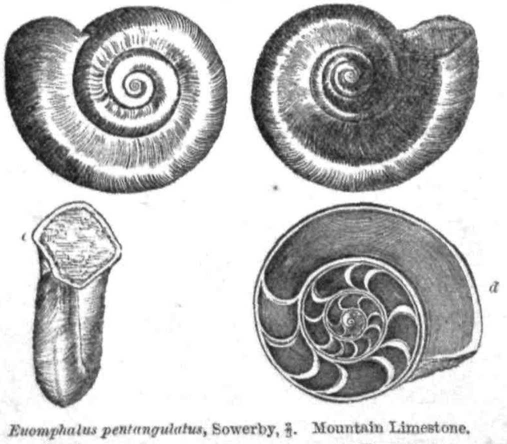
Aviculopecten sublobatus, Phill., nat. size. Carboniferous Limestone. Derbyshire; Yorkshire.

Fig. 488.

Pleurotomaria carinata, Sow., $\frac{2}{3}$. (*P. flammigera*, Phill.) Carboniferous Limestone. Derbyshire, &c.

Nucula (subgenus *Ctenodonta*), *Solemya*, *Modiola*, and *Lithodomus*, belong no doubt to existing genera.

a Fig. 489. b



Euomphalus pentangulatus, Sowerby, $\frac{2}{3}$. Mountain Limestone.

a. Upper side. *b.* Lower or umbilical side. *c.* View, showing mouth, which is less pentagonal in older individuals. *d.* View of polished section, showing internal chambers.

Gasteropoda.—These are represented by 206 species, and *Natica*, *Pleurotomaria*, *Macrocheilus*, and *Loxonema* are common.

Pleurotomaria carinata (fig. 488) is sometimes found with a pattern with wavy blotches, resembling the colouring in many recent Tops or *Trochidæ*.

Euomphalus is a characteristic univalve shell of this period. In the interior it is divided into chambers (fig. 489, *d*), the septa or partitions not being perforated as in foraminiferous shells, or in those having siphuncles, like the *Nautilus*. The animal appears to have advanced at different periods of its growth from the internal cavity previously formed, and to have closed all communication with it by a septum.. The number of chambers is irregular, and they are generally wanting in the innermost whorl.

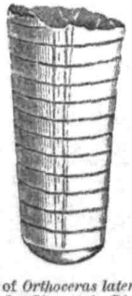
Fig. 490.

Bellerophon costatus, Sow. Nat. size. Mountain Limestone.

Heteropoda.—About twenty species of the genus *Bellerophon* (see fig. 490), a shell like the living *Argonaut* without chambers, occur in the Mountain Limestone. The genus is not met with in strata of later date. It is most generally regarded as belonging to the pelagic Heteropoda, and allied to the Glass-Shell, *Carinaria*.

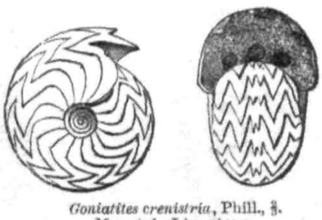
Cephalopoda.—Those of the carboniferous do not depart so widely from the living type (the *Nautilus*) as do the more ancient Silurian representatives of the same order; yet they offer some remarkable forms. Among these is *Orthoceras*, a siphuncled and chambered shell, like a *Nautilus* uncoiled and straightened (fig. 491). Some individuals of species of this genus are several

Fig. 491.



Portion of *Orthoceras laterale*, Phillips, ½. Mountain Limestone.

Fig. 492.



Goniatites crenistria, Phill., ⅜. Mountain Limestone. N. America; Britain; Germany, &c.

a. Lateral view.
b. Front view, showing the mouth.

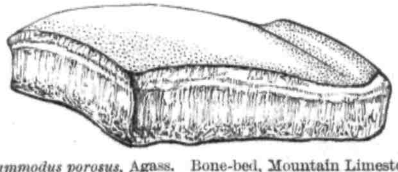
feet long. *Goniatites* is another genus, nearly allied to *Ammonites*, from which it differs in having the lobes of the septa free from lateral denticulations, or crenatures, but angular, and

uninterrupted in outline. The species represented in fig. 492 is found in most localities, and presents the zigzag character of the septal lobes in great perfection. The dorsal position of the siphuncle, however, clearly distinguishes the *Goniatite* from the *Nautilus*, and proves it to have belonged to the family Ammonitidæ.

Crustacea.—The great Crustacea of the Palæozoic age began to diminish in size and numbers during the Carboniferous period. One order, the Merostomata, in which the mouth was furnished with a masticating and seizing apparatus, the ends of which became walking or swimming feet, or organs of prehension, contained the genus Eurypterus, which will be noticed in dealing with the Devonian formation. There were also the genera *Prestwichia*, and *Belinurus*, which were Limuloid members of the order, and may belong to quite another group. Another order, the *Trilobita*, which was of great importance before the time of the Coal, began to diminish before the period, and only a few genera of the family Proelidæ lasted into it. They were—*Phillipsia*, *Griffithides*, and *Brachymetopus*. Some *Phyllopoda* and *Ostracoda* flourished during this age; and a Macrourous shrimp-like form lived in the Scottish Coal-measures.

Fossil Fish.—The distribution of these is singularly partial; so much so, that M. de Koninck, of Liége, once stated to me that, in making his extensive collection of the fossils of the Mountain Limestone of Belgium, he had found no more than four or five examples of the bones or teeth of fishes. Judging from Belgian data, he might have concluded that this class of vertebrata was of extreme rarity in the Carboniferous seas; whereas the investigation of other countries has led to quite a

Fig. 493.



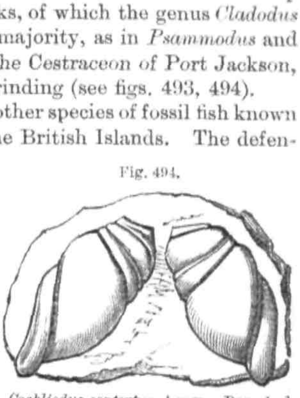
Psammodus porosus, Agass. Bone-bed, Mountain Limestone. Bristol; Armagh.

different result. Thus, near Clifton, on the Avon, as well as at numerous places around the Bristol basin, from the Mendip Hills to Tortworth, there is a celebrated 'bone-bed,' almost entirely made up of ichthyolites. It occurs at the base of the Lower Limestone shales immediately resting upon the upper

beds of the Old Red Sandstone. Similar bone-beds occur in the Carboniferous Limestone of Armagh, in Ireland, where they are made up chiefly of the teeth of Placoid fishes, nearly all of them rolled as if drifted from a distance. Some teeth are sharp and pointed, as in ordinary sharks, of which the genus *Cladodus* affords an illustration; but the majority, as in *Psammodus* and *Cochliodus*, are, like the teeth of the Cestraceon of Port Jackson, massive palatal teeth fitted for grinding (see figs. 493, 494).

There are upwards of seventy other species of fossil fish known in the Mountain Limestone of the British Islands. The defensive fin-bones of these creatures are not unfrequent at Armagh and Bristol; those known as *Oracanthus*, *Ctenacanthus*, and *Onchus* are often of a very large size. Ganoid fish, such as *Holoptychius*, also occur; but these are far less numerous. The great *Megalichthys Hibberti* appears to range from the Upper Coal-measures to the lowest Carboniferous strata.

Fig. 494.



Cochliodus contortus, Agass. Bone-bed Mountain Limestone. Bristol; Armagh.

Foraminifera.—In the upper part of the Mountain Limestone group in the S.W. of England, near Bristol, limestones having a distinct oolitic structure alternate with shales. In these rocks the nucleus of almost every minute spherule is seen, under the microscope, to consist of a small rhizopod or foraminifer. This division of the lower animals, which is represented so fully at later epochs by the Nummulites and their numerous minute allies, appears in the Mountain Limestone to be restricted to a few species, among which *Textularia*, *Nodosaria*, *Endothyra*, and *Fusulina* (fig. 495) have been recognised, but the number of individuals is vast. The first two genera are common to this and all the after periods; the third has been found in the Upper Silurian, but is not known above the Carboniferous strata; the fourth (fig. 495) is characteristic of the Mountain Limestone in the United States, Arctic America, Russia, and Asia Minor, and Japan, but is also known in the Permian. One of the Foraminifera with true nummuline structure has been discovered on the British area.

Fig. 495.

Fusulina cylindrica, D'Orb. Magnified 3 diam. Mountain Limestone.

Foreign Carboniferous Areas.—The Carboniferous deposits are well developed in Belgium and the North of France. In Central France there are numerous small patches of coal-

measures, and at Chalons, Autun, and St. Etienne the seams are very thick. In Germany, the Saarbrück coal-field is a detached part of the French measures. In Eastern Europe the Mountain Limestone is a series of shales resembling the culm or slaty coal of Devonshire. Its age is probably that of the calciferous deposits of Scotland. The Russian coal-fields are those of Tula and the Donetz. China has true Carboniferous rocks, but there are no true measures in India. Australia has them, however, in New South Wales. More than 200,000 square miles in the United States and British North America are Carboniferous.

CHAPTER XXVI.

DEVONIAN, OR OLD RED SANDSTONE FORMATION.

The Lacustrine and Marine areas—The Old Red Sandstone—Freshwater and the Devonian Marine formation—The old Lakes of Scotland and England—The Upper and Lower Old Red Sandstone groups—The Lower group—Fossil Fish and Crustaceæ—Plantæ—Marine Devonian—Divisions—Upper, Middle and Lower—Devonian of Russia, United States and Canada—Fossils—The intermediate nature of the Devonian fauna.

Classification of the types of the Devonian.—We have seen that the Carboniferous strata are surmounted by the Permian and Trias, which were originally called 'New Red Sandstone,' from the prevailing red colour of their deposits. Under the Lower Limestone shales of the Carboniferous formation, come other red sandstones and shales which were distinguished by the title of 'Old Red Sandstones.' Afterwards the name of Devonian was given by Mr. Lonsdale to marine formations, which in the south-west of England occupy an intermediate position between the Carboniferous and the underlying Silurian formation. It may be truly said that in the British Isles the rocks of this intermediate age present themselves in their mineral aspect, and mainly in their fossil contents, under two very different aspects, the one as distinct from the other as modern lacustrine or fluviatile strata are from marine deposits. The deposits of the Old Red Sandstone are of freshwater origin; and the character of the land plants and of the fishes, and the fact that the only shell yet discovered belongs to the *Anodonta*, must be allowed to lend no small countenance to this opinion. Moreover, the marine deposits are never found above or below these lacustrine strata, although often close by. Thick strata of freshwater and lacustrine origin,

separated, by natural barriers, from strata full of marine organisms and both being on the same geological horizon, peculiarised the Devonian formation as a whole. The strata of both of these areas accumulated contemporaneously, and the lakes were separated from the sea by high ground. The lacustrine area was well developed in Western and North-western Europe, and its floor was the upheaved Silurian sea bed. In the centre and south-west, marine conditions prevailed. In the lakes of the first locality, Old Red Sandstone accumulated, and in the seas and on the shores of the sea, the Marine Devonian was formed. Murchison divided the Old Red Sandstone into three divisions which he supposed were more or less contemporaneous with the three divisions of the Marine Devonian. But Geikie has shown that there are really only two divisions.

Geikie considers the Old Red Sandstone to have been deposited in separate basins or lakes, which were five in number. 1. Lake Orcadie, north of the Grampian Range, and including the Orkneys. 2. Lake Caledonia, occupying the central valley of Scotland between the Highlands to the north and the Silurian uplands to the south. It probably was prolonged across the Firth of Clyde into the north of Ireland. 3. Lake Cheviot; in the south-east of Scotland and north of England. 4. The Welsh Lake, bounded by the Silurian hills to the north and west. 5. Lake Lorne, a district in the north of Argyllshire, on the flanks of the South-west Highlands. The twofold division of the Old Red is seen typically in Lake Caledonia. The Upper Old Red merges gradually into the Lower Carboniferous strata above, and the Lower Old Red passes conformably into the Silurian formation below; but there is complete unconformity between the two series.[1]

Upper Old Red Sandstone.—The highest beds of the series in Scotland, lying immediately below the Carboniferous formation, consist of yellow and red sandstones and conglomerates, well seen at Dura Den, near Cupar, in Fife, where, although the strata contain no mollusca, fish have been found abundantly, and have been referred to *Holoptychius nobilissimus*,

[1] Geikie, Text-Book of Geology, from which much of this description has been abstracted. Geikie notices the occurrence in Lanarkshire of Silurian fossils—a Graptolite, *Spirorbis Lewisii* and *Orthoceras dimidiatum*—about 5,000 feet above the base of the Old Red. He states: 'This interesting fact serves to indicate that though geographical changes had elevated the Upper Silurian sea-floor, partly into land and partly into inland water-basins, the sea outside still contained an Upper Silurian fauna, which was ready on any favourable opportunity to re-enter the tracts from which it had been excluded.'

H. Andersoni, *Pterichthys major*, and to species of *Glyptopomus*, and others.

The number of individuals of species at Dura Den, crowded profusely through the pale sandstone, indicates, writes Professor A. Geikie, that the fish were killed suddenly and covered with sediment rapidly.

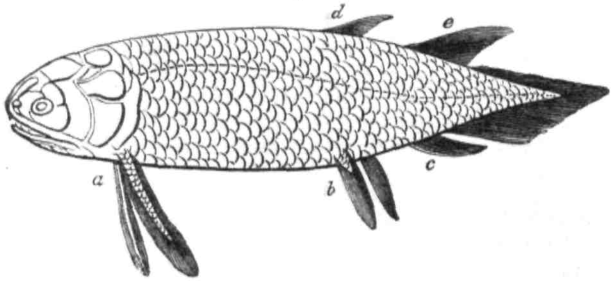
Fig. 496.

Scale of *Holoptychius nobilissimus*, Ag. Clashbinnie, ½ nat. size.

Sir R. Murchison groups with this upper division of the Old Red of Scotland, certain light-red and yellow sandstones and grits which occur in the northernmost part of the mainland and extend also into the Orkney and Shetland Islands. They contain *Calamites* and other plants which agree, generically, with Carboniferous forms, and overlie the Caithness flags unconformably. The Fish fauna of the Upper Old Red Sandstone numbers 25 species in 15 genera.

Geikie notices that a band of marine limestone of Devonian age, lying in the heart of the Old Red in Arran, is crowded with

Fig. 497.



Holoptychius. As restored by Professor Huxley.

a. The fringed pectoral fins. *c.* Anal fin.
b. The fringed ventral fins. *d, e.* Dorsal fins.

ordinary Carboniferous Limestone shells, such as *Productus giganteus*, *P. semireticulatus*; but none occur in the great series of sandstones overlying the limestone. These species do not reappear until we reach the limestones of the Carboniferous age, yet all these organisms must have been living before the deposition of the Arran limestone, and, of course, long prior to the formation of the Carboniferous limestone. This subject will be considered further on in relation to 'Colonies' (pp. 419 and 446).

Across the border districts, the sandstones and conglomerates of the Upper Old Red rest unconformably on Silurian rocks; and Lower Old Red Sandstone and breccias and conglomerates

appear under the Carboniferous formation along the flanks of the Cumberland and Westmoreland Hills, and in corresponding succession as far south as Flintshire and Anglesea.

The Lower Old Red Sandstone attains a depth of deposits in the great central basin (Lake Caledonia) of Scotland of 20,000 feet, and the strata present, everywhere, evidences of shallow-water conditions. There are proofs that local elevation occurred during the ages of general subsidence, which enabled the deposits to accumulate. In Lanarkshire, the strata rest on Silurian rocks conformably, elsewhere they are unconformable. The strata are red, brown, or chocolate-coloured, grey and yellow sandstones, red shales, grey flags, coarse conglomerates, and occasional beds of cornstone and limestone. The grey flags and thin grey and olive shales and 'calmstones' are almost confined to Forfarshire, and in the north-east part of the basin are known as Arbroath flags. One of the most marked features, writes Professor A. Geikie, is the occurrence of prodigious masses of interbedded volcanic rocks, having a thickness of more than 6,000 feet in this central basin. As a rule, the deposits of this basin are singularly unfossiliferous, though the Arbroath flags have been proved to be rich in the remains of fish and Crustacea. In Forfarshire and Perth, plant remains are found.

The Old Red Sandstone of the Northern Basin (Lake Orcadie) contains the dark grey bituminous schists and flagstones whose fossil fish were so interestingly described by the late Hugh Miller, and the calcareous flagstones of Caithness, resting on red sandstones and conglomerates. These last rest upon the up-tilted Silurian rocks.

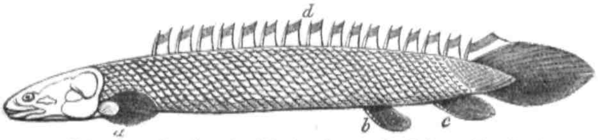
The Fish remains, which have made the Old Red Sandstone so interesting, mainly, but not entirely, belong to the lower division. Whilst the Upper Old Red has 25 species, the Lower Old Red contains 85 species distributed amongst 36 genera. In this division the Placoid fish are in 12 species, and all the rest belong to the Ganoids. In explanation, it may be said that Agassiz divided the Devonian fish into two great orders, namely, the Placoids and Ganoids. Of the first of these, which at the present time comprises the cartilaginous fish like the Shark, the Dog-fish, and the Ray, no skeletons are preserved; but fin-spines, called Ichthyodorulites, and teeth occur. On such remains, the genera *Onchus*, *Homacanthus*, *Ctenacanthus*, and *Cosmacanthus* have been established.

By far the greater number of the Old Red Sandstone fishes belong to a sub-order of Ganoids, called *Crossopterygidæ*[2] by

[2] From κροσσωτος, *crossotus*, a fringe, and πτερυξ, *pteryx*, a fin.

Huxley in 1861, or the fringe-finned, in consideration of the peculiar manner in which the fin-rays of the paired fins are arranged so as to form a fringe round a central lobe, as in the recent *Polypterus* (see *a*, fig. 498), a genus of which there are

Fig. 498.

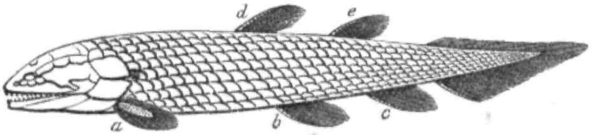


Polypterus. See Agassiz, 'Recherches sur les Poissons Fossiles.'
Living in the Nile and other African rivers.

a. One of the fringed pectoral fins. *c*. Anal fin.
b. One of the ventral fins. *d*. Dorsal fin, or row of finlets.

several species now inhabiting the Nile and other African rivers. The reader will at once recognise in *Osteolepis* (fig. 499), one of the common fishes of the Old Red Sandstone, many points of analogy with *Polypterus*. They not only agree in the structure of the fin, as first pointed out by Huxley, but also in the posi-

Fig. 499.



Restoration of *Osteolepis*. Pander. Old Red Sandstone, or Devonian.
a. One of the fringed pectoral fins. *c*. Anal fins.
b. One of the ventral fins. *d*, *e*. Dorsal fins.

tion of the pectoral, ventral, and anal fins, and in having an elongated body and rhomboidal scales. On the other hand, the tail is more symmetrical in the recent fish, which has also an apparatus of dorsal finlets of a very abnormal character, both as to number and structure. As to the dorsals of *Osteolepis*, they are two in number, which is unusual in living fish.

Among the 'fringe-finned' Ganoids we find some with rhomboidal scales, such as *Osteolepis*, figured above; others with cycloidal scales, as *Holoptychius* (figs. 496, 497). In the genera *Dipterus* and *Diplopterus*, as Hugh Miller pointed out, and in several other of the fringe-finned genera, as in *Gyroptychius* and *Glyptolepis*, the two dorsals are placed far backwards, or directly over the ventral and anal fins. The *Asterolepis* (one of the Placodermata) was a ganoid fish of large dimensions. *A. Asmusii*, Eichwald, a species character-

istic of the Old Red Sandstone (Devonian) of Russia, as well as of the same rocks in Scotland, attained, according to Hugh Miller,[3] the length of between twenty and thirty feet. They were partly clothed with strong bony armour, embossed with starlike tubercles. *Asterolepis* occurs also in the Devonian rocks of North America.

Amongst the interesting points which have been recorded about the ganoid fish, Professor Huxley has observed that, while a few of the Palæozoic and the majority of the Secondary Ganoids resemble the living Bony Pike, *Lepidosteus*, or the *Amia*, genera now found in North and Central American rivers, the Crossopterygidæ of the Old Red are closely related to the African *Polypterus* of the Nile and the rivers of Senegal. In 1870 another genus of the Crossopterygidæ, *Ceratodus Forsteri*, was found living in the rivers of Queensland, Australia.

If many circumstances favour the theory of the freshwater origin of the Old Red Sandstone, this view of its nature is not a little confirmed by our finding that it is in Lake Superior and the other inland Canadian freshwater seas, and in the Mississippi and African rivers, that we at present find those fish which have the nearest affinity to the fossil forms of this ancient formation.

Fig. 500.

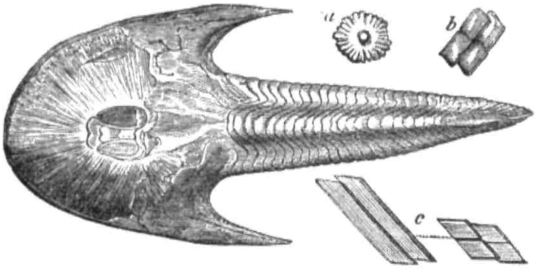
Pterichthys, Agassiz; Upper side, showing mouth; as restored by H. Miller.

Among the anomalous forms of Old Red fishes not referable to Huxley's Crossopterygidæ, and which are even doubtful Ganoids, having many structures which relate them to modern Siluroids amongst the Teleosteans, are the genera *Pterichthys*, *Cephalaspis*, *Pteraspis*, and *Coccosteus*. With regard to *Pterichthys*, some writers have compared its shelly covering to that of Crustaceans, with which, however, it has no real affinity. The wing-like appendages, whence the genus is named, were first supposed by Hugh Miller to be paddles, like those of the turtle; and there can now be no doubt that they do really correspond with the pectoral fins (fig. 500).

[3] Footprints of Creation, p. 103.

The genus *Cephalaspis*, or 'buckler-headed,' from the extraordinary shield which covers the head (fig. 501), has the orbits close together, nearly in the centre of the shield, which has a

Fig. 501.



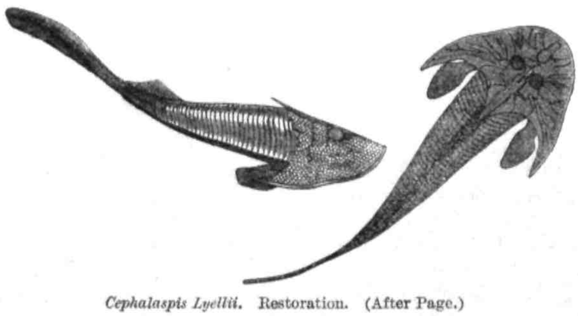
Cephalaspis Lyellii, Agass. Length 6¾ inches.

From a specimen in my collection found at Glamis, in Forfarshire. (See other figures, Agassiz, vol. ii. tab. 1 *a* and 1 *b*.)

a. One of the peculiar scales with which the head is covered when perfect. These scales are generally removed, as in the specimen above figured.
b, *c*. Scales from different parts of the body and tail.

horn on either side carried backwards. *Pteraspis*, of the same family, has also been found by the Rev Hugh Mitchell in Old Red beds, Perthshire; and it is interesting to note that this

Fig. 502.



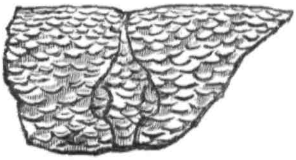
Cephalaspis Lyellii. Restoration. (After Page.)

genus came in during late Silurian times. Mr. Powrie enumerates no less than five genera of the sub-order Acanthodidæ, the spines, scales, and other remains of which have been detected in the grey flaggy sandstones, the genera being *Acanthodes*, *Diplacanthus*, and *Cheiracanthus*.

Fragments of a huge Crustacean have been met with, from

time to time in the Lower Old Red. They are called by the Scotch quarrymen the 'Seraphim,' from the wing-like form and feather-like ornament of the thoracic appendage, the part most usually met with.

Fig. 503.

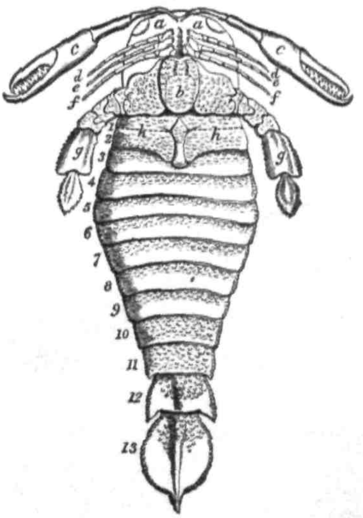


Pterygotus anglicus, Agassiz. Middle portion of the back of the head called the 'Seraphim.'

The relics belonged to *Pterygotus anglicus*, a huge form, of which the figure below is a restoration. The fossil, were it entire, would measure from 5 to 6 feet in length, and more than 1 foot across.

The largest Crustacea living at the present day, are the *Inachus Kæmpferi* of De Haan, from Japan (a brachyurous or short-tailed crab), chiefly remarkable for the extraordinary length of its limbs ; the fore-arm measuring 4 feet in length, and the others in proportion,

Fig. 504.



Pterygotus anglicus. Ag., Forfarshire. Ventral aspect. Restored by H. Woodward, F.R.S.

a. Carapace, showing the large sessile eyes at the anterior angles.
b. The *metastoma* or post-oral plate (serving the office of a lower lip).
c, *c*. Chelate appendages (*antennules*).
d. First pair of simple palpi (*antennæ*).
e. Second pair of simple palpi (*mandibles*).
f. Third pair of simple palpi (first *maxillæ*).
g. Pair of swimming feet with their broad basal joints, whose serrated edges serve the office of *maxillæ*.
h. Thoracic plate covering the first two thoracic segments, which are indicated by the figures 1, 2, and a dotted line.
1–6. Thoracic segments.
7–12. Abdominal segments.
13. Telson, or tail-plate.

so that it covers about 25 square feet of ground, and the *Limulus Moluccanus*, the great King Crab of China and the Eastern seas, which, when adult, measures 1½ foot across its carapace, and is 3 feet in length.

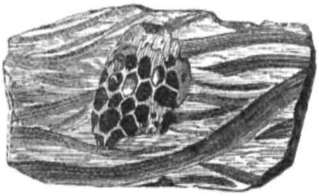
Besides some species of *Pterygotus*, several of the allied

genus *Eurypterus* occur in the Lower Old Red Sandstone. These Crustacea of the Old Red are of the sub-order Eurypteroida, and belong to the order Merostomata. They are accompanied by fossils, called 'berries' by the quarrymen, which they compare to a compressed blackberry (see figs. 505, 506, and 507), and which were called 'Parka' by Dr. Fleming.

Fig. 505.

Parka decipiens, Fleming. In sandstone of lower beds of Old Red, Ley's Mill, Forfarshire.

Fig. 506.

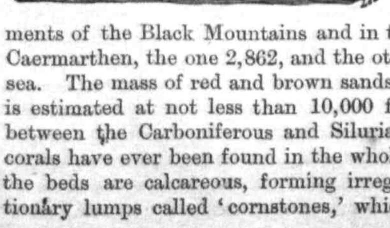


Parka decipiens, Fleming, nat. size. In shale of Lower Old Red, Park Hill, Fife.

They are now considered by Mr. Powrie to be the eggs of Crustacea; which is highly probable, for they have not only been found with *Pterygotus anglicus* in Forfarshire and Perthshire, but also in the Upper Silurian strata of England in which species of the same genus, *Pterygotus*, occur.

The grandest exhibitions, says Sir R. Murchison, of the Old Red Sandstone in England and Wales appear in the escarp-

Fig. 507.



Old Red Sandstone Shale of Forfarshire. With impression of plants and ova of Crustaceans. Nat. size.

a. Two pair of ova? resembling those of large Salamanders or Tritons—on the same leaf.

b, *b*. Detached ova.

ments of the Black Mountains and in the Vans of Brecon and Caermarthen, the one 2,862, and the other 2,590 feet above the sea. The mass of red and brown sandstone in these mountains is estimated at not less than 10,000 feet, clearly intercalated between the Carboniferous and Silurian strata. No shells or corals have ever been found in the whole series, not even where the beds are calcareous, forming irregular courses of concretionary lumps called 'cornstones,' which may be described as

mottled red and green earthy limestones. The fishes of this lowest English Old Red are *Cephalaspis* and *Pteraspis*, specifically different from species of the same genera which occur in the uppermost Ludlow or Silurian tilestones. Crustaceans also of the genus *Eurypterus* are met with.

Besides the bodies called *Parka decipiens*, there are the spore-cases or the floats of a lowly organised plant called *Pachytheca*.

The Old Red strata merge into Carboniferous Limestone shale above, and into the Uppermost Silurian strata below.

In Ireland, as in Scotland, the upper division of the Old Red Sandstone lies unconformably upon the lower, and in South Wales the upper beds overlap the lower strata, 'indicating,' wrote Sir A. Ramsay, 'great disturbance and denudation,' but not presenting any insuperable difficulty as to the freshwater origin of the strata.

A dearth of calcareous matter over wide areas, is characteristic of the Old Red Sandstone. This is, no doubt, in great part due to the absence of marine deposits and the scarcity of freshwater lime-forming animals.

In the county of Cork, in Ireland, a similar yellow sandstone occurs containing fish of genera characteristic of the Scotch Old Red Sandstone, as for example *Coccosteus* (a form represented by many species in the Old Red Sandstone and by one only in the Carboniferous group) and *Glyptolepis*, which is exclusively confined to the 'Old Red.' In the same Irish sandstone at Kiltorkan has been found an *Anodonta* or freshwater Mussel, the only shell hitherto discovered in the Old Red Sandstone of the British Isles (see fig. 508). In the same beds are found the Fern (fig. 510) and the *Lepidodendron* (fig. 509), and twelve other species of plants, some of which, Professor Heer remarks, agree specifically with species from the Lower Carboniferous beds. This induces him to lean to the opinion, long ago advocated by Sir Richard Griffith, that the yellow sandstone, in spite of its fish remains, should be classed as Lower Carboniferous—an opinion which I am not yet prepared to adopt. Between the Mountain Limestone and the yellow sandstone in the South-west of Ireland there intervenes a formation no less than 5,000 feet thick, called the 'Carboniferous slate;' and at the base of this, in some places, are local deposits, such

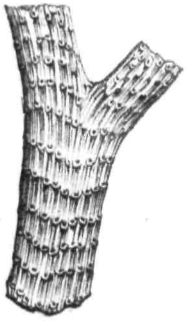
Fig. 508.

Anodonta Jukesii, Forbes, ½.
Upper Devonian, Kiltorkan, Ireland.

as the Coomhola Grits, which appear to be beds of passage between the Carboniferous and Old Red Sandstone groups.

It is a remarkable result of the recent examination of the fossil flora of Bear Island, lat. 74° 30′ N., that Professor Heer has described as occurring in that part of the Arctic region

Fig. 509.



Bifurcating branch of *Lepidodendron Griffithsii*, Brong. Upper Devonian, Kilkenny.

Fig. 510.

Palæopteris Hibernica, Schimp. (*Cyclopteris Hibernica*, Ed. Forbes.) (*Adiantites*, Goep.) Upper Devonian, Kilkenny.

(nearly twenty-six degrees to the north of the Irish locality) a flora agreeing in several of its species with that of the yellow sandstones of Ireland. This Bear Island flora is believed by Professor Heer to comprise species of plants some of which ascend even to the higher stages of the European Carboniferous formation, or as high as the Mountain Limestone and Millstone Grit. Palæontologists have long maintained that the same species which have a wide range in space are also the most persistent in time, which may prepare us to find that some plants having a vast geographical range may also have endured from the period of the Upper Devonian to that of the Millstone Grit.

The Flora of the Old Red Sandstone is poor, but extremely interesting from its foreshadowing the later grand Carboniferous flora.

In the Upper Old Red there are only 12 species of plants, and the following genera are represented:—*Adiantites*, *Calamites*, *Filicites*, *Sageneria*, *Sphenopteris*, *Trichomanites* and *Knorria*. The Lower division contains *Lepidodendron*, also a Coniferous plant, and an Alga called *Psilophyton*, to be noticed further on.

Marine or Devonian Type.—We may now speak of the marine type of the British strata intermediate between the Carboniferous and Silurian formations. The Marine Devonian is divided into Upper, Middle, and Lower series, and they are readily identified with corresponding foreign equivalents. It was not until the year 1836 that Sir R. Murchison and Professor Sedgwick discovered that the culmiferous or anthracitic shales and sandstones of North Devon, several thousand feet thick, belonged to the Coal; and that the beds below them, which are of still greater thickness, and which, like the Carboniferous strata, had been confounded under the general name 'greywacke,' occupied a geological position corresponding to that of the Old Red Sandstone already described. This reform was inevitable, in consequence of the discovery by Mr. Lonsdale that the Devonshire fossils belonged to a peculiar palæontological type, of intermediate character, between the Carboniferous and Silurian.

It is in the north of Devon that these formations may best be studied, where they have been divided into an Upper, Middle, and Lower Group, and where, although much contorted and folded, they have for the most part escaped being altered by intrusive trap-rocks and by granite, which in Dartmoor and the more southern parts of the same county, have often reduced them to a crystalline or metamorphic state.

The following table, mainly due to Mr. Etheridge's admirable work, exhibits the sequence of the strata or subdivisions as seen both on the sea-coast of the British Channel and in the interior of Devon.

DEVONIAN SERIES IN NORTH DEVON.

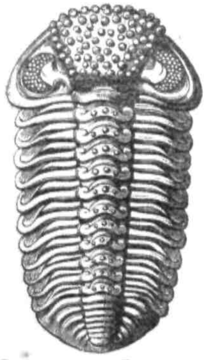
Upper Devonian or Pilton Group.	(*a*) Sandy slates and schists with fossils, many species common to the Carboniferous group (Pilton, Barnstaple, &c.), resting on soft schists in which fossils are very abundant (Croyde, &c), and which pass down into
	(*b*) Yellow, brown, and red sandstone, with land plants (*Cyclopteris*, &c.) and marine shells. One zone, characterised by the abundance of *Cucullæa* (Baggy Point, Marwood, Sloly, &c.), resting on hard grey and reddish sandstone and micaceous flags; no fossils yet found (Dulverton, Pickwell, Down, &c.).
Middle Devonian or Ilfracombe Group.	(*a*) Grey glossy slates of considerable thickness, bearing quartz veins; no fossils yet recorded from these beds (Morthoe, Lee Bay, &c.).
	(*b*) Slates and schists, with irregular courses of limestone containing shells and corals like those of the Torbay and Plymouth Limestone (Combe Martin, Ilfracombe, &c.).

Lower Devonian or Lynton Group.	(*a*) Hard, greenish, red, and purple sandstone (Hangman Hill, &c.). (*b*) Soft slates with subordinate sandstones—fossils numerous at various horizons—Brachiopoda, Corals, Encrinites, &c. (Valley of Rocks, Lynmouth, &c.).

The total thickness is very great, probably 9,000 feet.

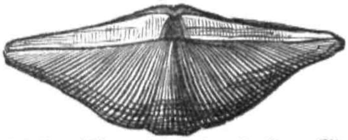
Upper Devonian Rocks.—The slates and sandstones of Barnstaple (*a* and *b* of the preceding section) contain the Brachiopod, *Spirifera disjuncta*, Sow. (fig. 512), which has a very wide range in Europe, Asia Minor, and even China; also *Strophalosia caperata*, together with the large Trilobite *Phacops latifrons*, Bronn. (fig. 511), which is all but world-wide in its distribution. The fossils are numerous, and comprise about 150 species of mollusca, a fifth of which pass up into the overlying Carboniferous rocks. To this Upper Devonian belong a series of limestones and slates well developed at Petherwyn, in Cornwall, where they have yielded 75 species of fossils. The genus of Cephalopoda called *Clymenia* (fig. 513) is represented by no less than 11 species, and strata

Fig. 511.



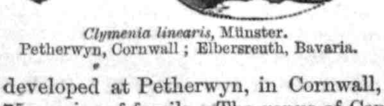
Phacops latifrons, Bronn, nat. size. Characteristic of the Devonian in Europe, Asia, and N. and S. America.

Fig. 512.



Spirifera disjuncta, Sow. Syn. *Sp. Verneuilii*, Murch. ½. Upper Devonian, Boulogne.

Fig. 513.



Clymenia linearis, Münster. Petherwyn, Cornwall; Elbersreuth, Bavaria.

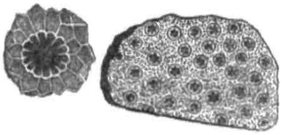
Fig. 514.

Cypridina serrato-striata, Sandberger, Weilburg, &c.; Cornwall; Nassau; Saxony; Belgium.
a. Nat. size.

occupying the same position in Germany are called Clymenien-Kalk, or sometimes Cypridinen-Schiefer, on account of the number of minute bivalve shells of the Crustacea called *Cypridina serrato-striata* (fig. 514), which is found in these beds, in the Rhenish provinces, the Harz, Saxony, and Silesia, as well as in Cornwall and Belgium.

Middle Devonian Rocks.—We come next to the most typical portion of the Devonian system, including the great limestones of Plymouth and Torquay, as well as the slates and impure

a Fig. 515.



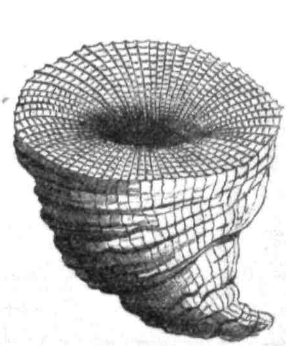
Heliolites porosa, Goldf., sp. (*Porites pyriformis*, Lonsd.), nat. size.
a. One of the corallites magnified. Middle Devonian, Torquay. Plymouth, Eifel.

limestones of Ilfracombe, all replete with shells, Trilobites, and corals. Of the corals 52 species are enumerated by Mr. Etheridge, none of which pass into the Carboniferous formation above or came from the Silurian strata below, although many

Fig. 516.

Favosites cervicornis, Blainv., nat. size. S. Devon, from a polished specimen. A Tabulate Coral (*Hydrozoan*).
a. Portion of the same magnified, to show the tabulæ and pores.

Fig. 517.

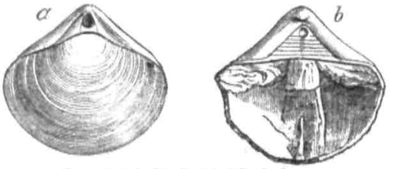


Heliophyllum Halli. A Rugose Coral. Middle Devonian. After Nicholson.

genera are common to the formations. Among the genera are *Favosites*, *Heliolites*, *Smithia*, *Heliophyllum*, and *Cyathophyllum*. The *Heliophyllum Halli*, a Rugose Coral (fig. 517), and *Heliolites porosa*, an Alcyonarian (fig. 515), are species peculiar to this formation.

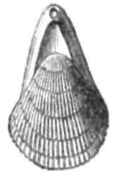
Stromatopora occurs, and a few Bryozoa. With the above are found no less than 10 genera of Echinodermata, 6 of which are stone-lilies or Crinoids; some of them, such as *Cupressocrinites*, are distinct from any Carboniferous forms. The mollusca also are less characteristic; of 26 genera of Brachiopoda, 19 are common to the Carboniferous series. The *Stringocephalus Burtini* (fig. 518) and *Uncites gryphus* (fig. 519) may be mentioned as exclusively Middle Devonian genera, and extremely characteristic of the same division in Belgium. The *Stringocephalus* is also so abundant in the Middle Devonian of the banks of the Rhine as to have suggested the name of Stringocephalus Limestone. The only two species of Brachiopoda common to the Silurian and Devonian formations are *Atrypa reticularis*, which seems to have been a cosmopolitan species, and *Strophomena rhomboidalis*.

Fig. 518.



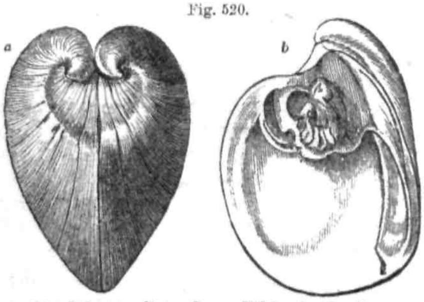
Stringocephalus Burtini, Def., ½.
a. Valves united. *b.* Interior of ventral or large valve, showing thick partition and portion of a large process which projects from the dorsal valve across the shell.

Fig. 519.



Uncites gryphus, Def., ⅔. Middle Devonian. S. Devon and the Continent.

Fig. 520.



Megalodon cucullatus, Sow. Eifel; also Bradley, S. Devon.
a. The valves united.
b. Interior of valve, showing the large cardinal tooth.

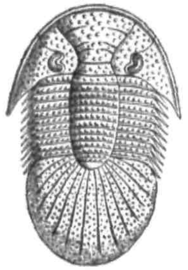
Fig. 521.

Conularia ornata, D'Arch. and De Vern, ⅔. Refrath, near Cologne.

Among the lamellibranchiate bivalves common to the Ply-

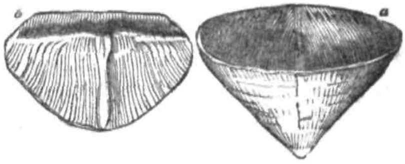
mouth limestone of Devonshire and the Continent, we find the *Megalodon* (fig. 520). There are also 13 genera of Gasteropoda which have yielded 45 species, 5 of which pass to the Carboniferous group, namely, *Acroculia vetusta*, *Loxonema rugiferum*, *L. tumidum*, *Murchisonia angulata* and *M. spinosa*. The Pteropod *Tentaculites* occurs in England, and on the Continent there is the genus *Conularia* (fig. 521). The Cephalopods have species of *Cyrtoceras*, *Goniatites*, *Orthoceras*, *Nautilus*, and nearly all of them are distinct from those in the Upper Devonian Limestone, or Clymenien-Kalk of the Germans, already mentioned. Although but 6 species of Trilobites occur, the characteristic *Bronteus flabellifer* (fig. 522) is far from rare, and all

Fig. 522.



Bronteus flabellifer, Goldf.
Mid. Devon; S. Devon; and the Eifel.

Fig. 523.



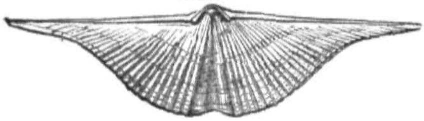
Calceola sandalina, Lam., ⅔. Eifel; also South Devon.
a. Ventral valve.
b. Inner side of dorsal valve.

collectors are familiar with its fan-like tail. In this same group, called, as before stated, the Stringocephalus or Eifel Limestone in Germany, several fish remains have been detected, and among others the remarkable Old Red genus *Coccosteus*, covered with its tuberculated bony armour; and these ichthyolites serve, as Sir R. Murchison observes ('Siluria,' p. 362), to identify this middle marine Devonian with the Old Red Sandstone of Britain and Russia.

Beneath the Eifel Limestone (the great central and typical member of the 'Devonian' on the Continent) lie certain schists called by German writers 'Calceola-Schiefer,' containing in abundance *Calceola sandalina* (fig. 523), which has been usually considered a Brachiopod, but which some naturalists have lately referred to the Operculate corals. This is by no means a rare fossil in the slaty limestone of South Devon, and, like the Eifel form, is confined to the middle group of the formation in this country.

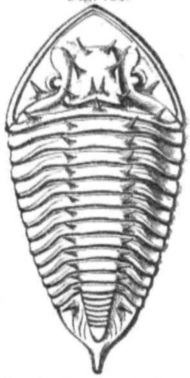
Lower Devonian Rocks.—A great series of sandstones and glossy slates, with Crinoidea, Brachiopoda, and some corals

Fig. 524.



Spirifera mucronata, Hall, nat. size. Devonian of Pennsylvania.

Fig. 525.



Homalonotus armatus, Burmeister, ⅓. Lower Devonian; Daun, in the Eifel; and S. Devon.

and Bryozoa, occurring on the coast at Lynmouth and the neighbourhood, and called the Lynton Group (see table, p. 412), form the lowest member of the Devonian in North Devon. Traces of fish remains occur, and *Pteraspis*, a genus of Silurian Fish, has been detected. Among the 18 species of all classes enumerated by Mr. Etheridge, two-thirds are common to the Middle Devonian; but only one, the ubiquitous Brachiopod *Atrypa reticularis*, can be identified with Silurian species. Among the characteristic forms are *Aveolites suborbicularis*, also common to this formation in the Rhine, and *Orthis arcuata*, very widely spread in the North Devon localities. But we may expect a large addition to the number of fossils, whenever these strata shall have been carefully searched. The Spirifer-sandstone of Sandberger, as exhibited in the rocks bordering the Rhine between Coblentz and Caub, belong to this Lower division, and the same broad-winged Spirifers distinguish the Devonian strata of North America.

Among the Trilobites of this era are the genera *Phacops*, and several large species of *Homalonotus* (fig. 525) are conspicuous. The genus is still better known as a Silurian form, but the spinose species appear to belong exclusively to the 'Lower Devonian,' and are found in Britain, Europe, and the Cape of Good Hope.

Devonian of Russia.—The Devonian strata of Russia extend, according to Sir R. Murchison, over a region more spacious than the British Isles; and it is remarkable that, where they consist of sandstone like the 'Old Red' of Scotland and Central England, they are tenanted by fossil fishes often of the same species and still oftener of the same genera as the British, whereas when they consist of limestone they contain shells similar to those of Devonshire, thus confirming, as Sir Roderick

has pointed out, the contemporaneous origin which had been previously assigned to formations exhibiting two very distinct mineral types *in different parts of Britain.*[4] The calcareous and the arenaceous rocks of Russia above alluded to, alternate in such a manner as to leave no doubt of their having been deposited in different parts of the same great period.

Devonian Strata in the United States and Canada.—Between the Carboniferous and the Silurian strata in the United States and Canada, there intervenes a great series of formations referable to the Devonian group, comprising some marine strata abounding in shells and corals, and others of shallow-water and littoral origin, in which terrestrial plants abound. The fossils, both of the deep and shallow-water strata, are very analogous to those of Europe, the species being in some cases the same. In Eastern Canada Sir W. Logan has pointed out that in the peninsula of Gaspé, south of the estuary of the St. Lawrence, a mass of sandstone, conglomerate, and shale referable to this period occurs, rich in vegetable remains, together with some fish-spines. Far down in the sandstones of Gaspé Dr. Dawson found in 1869 an entire specimen of the genus *Cephalaspis*, a form so characteristic, as we have already seen, of the Scotch Lower Old Red Sandstone. Some of the sandstones are ripple-marked; and towards the upper part of the whole series a thin seam of coal has been observed, measuring, together with some associated carbonaceous shale, about three inches in thickness. It rests on an under-clay in which are the roots of *Psilophyton* (see fig. 526). At many other levels, rootlets of this same plant have been shown, by Principal Dawson, to penetrate the clays, and to play the same part as the rootlets of *Stigmaria* in the coal formation.

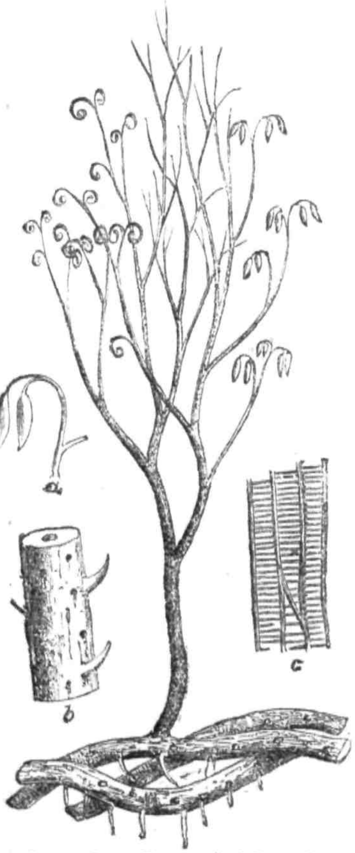
We had already learnt from the works of Göppert, Unger, and Bronn, that the European plants of the Devonian epoch resemble generically, with few exceptions, those already known as Carboniferous; and Dr. Dawson, in 1859, enumerated 32 genera and 69 species which he had then obtained from the State of New York and Canada. A perusal of his catalogue,[5] comprising *Coniferæ*, *Sigillariæ*, *Calamites*, *Asterophyllites*, *Lepidodendra*, and ferns of the genera *Cyclopteris*, *Neuropteris*, *Sphenopteris*, and others, together with fruits, such as *Cardiocarpon* and *Trigonocarpon*, might dispose geologists to believe that they were presented with a list of Carboniferous fossils, the difference of the species from those of the Coal-measures, and even a slight admixture of genera unknown in Europe, being

[4] Murchison's Siluria, p. 329.

[5] Quart. Journ. Geol. Soc. vol. xv. 447, 1859; also vol. xviii. p. 296, 1862.

naturally ascribed to geographical distribution and the distance of the New from the Old World. But fortunately the Coal formation is fully developed on the other side of the Atlantic, and is singularly like that of Europe, both lithologically and in the species of its fossil plants. There is also the most unequivocal evidence of relative age afforded by superposition, for the Devonian strata in the United States are seen to crop out from beneath the Carboniferous on the borders of Pennsylvania and New York, where both formations are of great thickness.

Fig. 526.



Psilophyton princeps, Dawson, Geol. Quart. Journ. Soc. vol. xv. 1863; and Canada Survey, 1863. Species characteristic of the whole Devonian series in North America.
a. Fruit; natural size. *b*. Stem; natural size. *c*. Scalariform tissue of the axis, highly magnified.

The number of American Devonian plants has now been raised by Dr. Dawson and others to 160, to which we may add about 80 from the European flora of the same age, so that already the vegetation of this period is beginning to be nearly half as rich as that of the Coal-measures which have been studied for so much longer a time and over so much wider an area. The *Psilophyton* above alluded to, is believed by Dr. Dawson to be a Lycopodiaceous plant, but Carruthers considers it to have been an Alga. Its remains have been traced through all the members of the Devonian series in America, and Dr. Dawson has lately recognised it in specimens of Old Red Sandstone from the north of Scotland.

Devonian Insects.—The earliest known insects were brought to light in 1865 in the Devonian strata of St. John's, New Brunswick, and are referred by Mr. Scudder to the group *Pseudo-neuroptera.* One of them, a *Platephemera*, measured five inches in expanse of wing. It was an ancient May Fly with some additional structures.

The genus *Xenoneura* has a remarkable union of structures which are found in different genera at the present day. It is a lace-winged form of the May Fly group, furnished with a stridulating or musical organ like a Grasshopper. Such a genus is said to be synthetic. With regard to the stridulating apparatus, Dr. Dawson observes, if it is rightly interpreted by Mr. Scudder, it introduces us to the sounds of the Devonian woods, bringing before our imagination the trill and hum of insect life that enlivened the solitudes of these strange old forests.

There were no Amphibia or Reptilia during the Devonian age, and Fish were the only vertebrated animals. The huge armoured placoid fish dominated, and were greatly diminished in numbers at the close of the age, being replaced by the Elasmobranchs—Sharks, Rays, and Chimæras, which dominated subsequently during the Carboniferous period.

It was noticed that a limestone in the Upper Old Red Sandstone of Scotland contained species which did not reappear in the overlying sandstones, but which have been found much higher in the Carboniferous Limestone series. Now in the Lower Old Red of Lanarkshire, a thin bed of shale occurs about 5,000 feet above the base of the formation, containing a *Graptolite* and *Spirorbis Lewisii* and *Orthoceras demidiatum*; and these are Upper Silurian forms. The Old Red deposits were lacustrine, and it must be supposed that in both of the instances above mentioned, the sea breached in for a while, and the marine fauna of the time prevailed, and some of its members became subsequently fossil. But the invading creatures were Silurian in one instance and Carboniferous in the other, and not Devonian; and we are obliged to believe that the marine Devonian fauna was not then existing. We must believe that the Silurian fauna had lasted on in the North, and was succeeded by a Carboniferous marine fauna. If the marine Devonian fauna ever existed in those regions, it should have appeared during the time indicated by the deposits between the above-mentioned shale and limestone. It is evident that these interesting deposits are unique. Formerly, much discussion occurred because Old Red lacustrine fish were found in the Marine Devonian, but now the example of the Salmonidæ in frequenting both fresh and salt water has removed the difficulty

of explaining the presence of fossils considered to be of fresh-water origin in marine strata. The intermediate yet isolated character of the Devonian formation is shown by the fact that in Great Britain it contains 196 genera and 544 species. Of these 32 genera and 51 species pass up into the Carboniferous strata, whilst 12 genera and 20 species came from the Upper Silurian.

CHAPTER XXVII.

SILURIAN GROUP.

Classification of the Silurian rocks—Upper Silurian rocks—Ludlow formation and fossils—Bone-bed of the Upper Ludlow—Lower Ludlow shales with *Pentamerus*—Oldest known remains of vertebrata—Wenlock formation—Fossils—Upper and Lower Llandovery groups—Lower Silurian rocks—Caradoc and Bala beds—The fauna—The Trilobita and their structure—The Llandeilo series—The Arenig or Stiper-stones group—The important fauna—The Ordovician—The volcanic series of Wales—The Lake District Silurians—Southern Highlands—European Silurians—Russia—Bohemia—United States Silurians—Canada—Barrande's doctrine of colonies.

Classification of the Silurian rocks.—We come next in descending order to that division of Primary or Palæozoic rocks which immediately underlies the Devonian group or Old Red Sandstone.

Sir Roderick Murchison gave the name of Silurian to the strata beneath the Devonian, and it is clear that these great groups are distinct formations, for only twenty species of organisms, out of 392 which existed during Silurian times, lived on into the Old Red Sandstone age. Moreover, whilst in Shropshire and Herefordshire the deposits of the uppermost Silurian strata and of the lowest Old Red merge conformably, there is evident unconformity in Denbighshire.

The strata underlying the Devonian may be divided into many groups, but there is no such a palæontological break between any in the succession, as there is between the Silurian and Devonian. In one instance, between two groups called Lower and Upper Llandovery (p. 430), there is evident unconformity; yet one half of the species of the Lower pass up into the Upper Llandovery rocks, the palæontological break being inconsiderable. Beneath the Lower Llandovery strata are those of the Bala and Caradoc groups, and local unconformity has been traced between them. Mr. Etheridge has carefully analysed the fauna of these two groups, and finds that the greatest number

of species, which passed from the Caradoc into the Lower Llandovery strata was about 105 out of 614.

This palæontological break is not equal to that between the Silurian and Devonian, or between the Cretaceous and the Tertiary series. It is remarkable that as many Caradoc species pass through into the Upper Llandovery as into the Lower Llandovery rocks.

The Llandeilo beds underlie the Caradoc, or Bala, strata, and 73 species out of 175 of the first pass upwards into the last-named, so that there is a greater proportion of transgressing species than there is between the Caradoc and Lower Llandovery. The Arenig or 'Stiper-stones' strata, beneath the Llandeilo, contain a remarkable and isolated fauna, for out of 150 species only 9 pass into the succeeding Llandeilo beds, and 16 were derived from lower strata belonging to the Tremadoc strata, which are conformable in stratification. These Tremadoc strata are connected palæontologically, with the Lingula Flags beneath them, and there is no stratigraphical break between them. The Lingula Flags rest on the Menevian group, and those on Longmynd, or Harlech rocks, the oldest fossiliferous strata in Europe. Although nearly all these sets of strata are linked together palæontologically their lithology differs. Moreover, most of them contain some special forms which seem to have appeared for the first time, and in some instances to have died out. There was not that struggle for existence which occurred later on in the world's history, and therefore species were enabled to survive under circumstances which assuredly would have either developed variation or produced extinction, later on. The hard-and-fast lines required by classificatory geologists are not found applicable in the succession of strata beneath the Devonian, and therefore all the so-called formations or series which bear the names of Murchison, Sedgwick, and others are arbitrary in their application, and artificial.

Murchison considered all the groups of strata from the Ludlow to the Lowest Lingula Flags, including the Menevian, to be of one great system, the Silurian. Below it were the Longmynd or Harlech strata of the Cambrian. He made the Llandovery groups transitional or passage beds between the Upper and Lower Silurian. Sedgwick, before Murchison, had included the groups below the Llandovery groups, as far down as and including the oldest known fossiliferous rocks of the Harlech and Longmynd group, in the Cambrian formation, and he considered all above the Lower Llandovery series to be Silurian.

In this work the classification adopted has been to consider

that the Upper Silurian formation reaches down to the base of the Lower Llandovery rocks, and that the Lower Silurian rests upon the Tremadoc strata, having the Arenig group as its lowest member. It is certain that these limits refer to the greatest of the breaks in the series of groups, and it appears to be the palæontological break at the base of the Arenig which prevents the classification of Sedgwick being adopted universally.

The following table will explain the two principal divisions, Upper and Lower, of the Silurian rocks, and the minor subdivisions usually adopted, comprehending all the strata originally, but not subsequently, embraced in the Silurian system by Sir Roderick Murchison.

UPPER SILURIAN ROCKS.

	Thickness in feet.
1. Ludlow Formation:	
a. Upper Ludlow beds	1950
b. Lower Ludlow beds	
2. Wenlock Formation:	
a. Wenlock limestone and shale	
b. Woolhope limestone and shale, Tarannon shale, and Denbighshire grits	above 4,000
3. Llandovery Formation (Beds of passage between Upper and Lower Silurian):	
a. Upper Llandovery (May Hill beds)	2500
b. Lower Llandovery	

LOWER SILURIAN ROCKS.

1. Bala and Caradoc Beds, including volcanic rocks	6,000
2. Llandeilo Flags, including volcanic rocks	2,500
3. Arenig or Stiper-stones Group, including volcanic rocks	4,000

UPPER SILURIAN ROCKS.

1. **Ludlow Formation.**—This has been subdivided into two parts—the Upper Ludlow and the Lower Ludlow. Each of these may be distinguished near the town of Ludlow, and at other places in Shropshire and Herefordshire, by peculiar organic remains; but out of 392 species found in the Ludlow formation as a whole, not more than five species per cent. are common to the overlying Devonian, and nearly all of those are fish and *Crustacea*. On the other hand, 129 of these species lived in the underlying Wenlock deposits.

a. **Upper Ludlow,** *Downton Sandstone.*—At the top of this subdivision there occur beds of fine-grained yellowish sandstone and hard reddish grits which were formerly referred by Sir R.

Murchison to the Old Red Sandstone, under the name of 'Tilestones.' In mineral character this group forms a transition from the Silurian to the Old Red Sandstone; but it is now ascertained that the fossils agree in great part specifically, and in general character entirely, with those of the underlying Upper Ludlow rocks, many passing upwards. Among these are *Orthoceras bullatum*, *Platyschisma helicites*, *Bellerophon trilobatus*, *Chonetes latus*, &c., Crustacea of the genera *Pterygotus*, *Eurypterus* and *Stylonura* are met with; and Fish—*Cephalaspis*, *Pteraspis*, *Scaphaspis*, *Auchenaspis*, and *Eukeraspis*.

Bone-bed of the Upper Ludlow.—At the base of the Downton sandstones there occurs a bone-bed which deserves especial notice as affording the most ancient example of fossil fish occurring in any considerable quantity. It usually consists of one or two thin layers of brown bony fragments near the junction of the Old Red Sandstone and the Ludlow rocks. It is seen near the town of Ludlow, where it is three or four inches thick, and has been traced to a distance of 45 miles from that point into Gloucestershire and other counties, and is commonly not more than an inch thick, but varies to nearly a foot. Near Ludlow two bone-beds are observable, with 14 feet of intervening strata full of Upper Ludlow fossils.[1] Immediately above the upper fish-bed numerous small globular bodies have been found, which are considered by Sir J. Hooker and Mr. Carruthers to be the sporangia of a lycopodiaceous land-plant, *Pachytheca sphærica*.

Some of the fish remains are of the placoid order, and may be referred to the genus *Onchus*, to which the spine (fig. 527)

Fig. 527.

Onchus tenuistriatus, Agass., nat. size. Bone-bed. Upper Silurian; Ludlow.

Fig. 528.

Shagreen scales of a placoid fish, *Thecodus parvidens*, Ag. Bone-bed. Upper Ludlow.

belongs. The minute scales (fig. 528) may also belong to a placoid fish. The jaw and teeth of another predaceous genus, *Plectrodus mirabilis* (fig. 529), have also been detected, together with some specimens of *Pteraspis Ludensis*. As is usual in bone-beds, the teeth and bones are, for the most part, fragmentary and rolled. Associated with these fish defences or Ichthyodorulites, and closely resembling them, are numerous prongs or tail spines of large phyllopod crustaceans

Fig. 529.

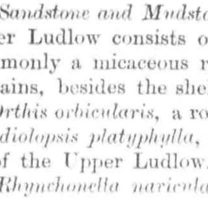
Plectrodus mirabilis, Agass. Nat. size. Bone-bed. Upper Ludlow.

1 Murchison's Siluria, p. 140.

which have been and are still frequently mistaken for the dorsal spines of fish.

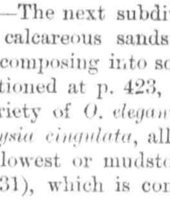
Grey Sandstone and Mudstone, &c.—The next subdivision of the Upper Ludlow consists of grey calcareous sandstone, or very commonly a micaceous rock, decomposing into soft mud, and contains, besides the shells mentioned at p. 423, *Lingula cornea*, *Orthis orbicularis*, a round variety of *O. elegantula* (fig. 530), *Modiolopsis platyphylla*, *Grammysia cingulata*, all characteristic of the Upper Ludlow. The lowest or mudstone beds contain *Rhynchonella navicula* (fig. 531), which is common to

Fig. 530.



Orthis elegantula, Dalm., nat. size.
Var. *Orbicularis*, Sow. Upper Ludlow.

Fig. 531.

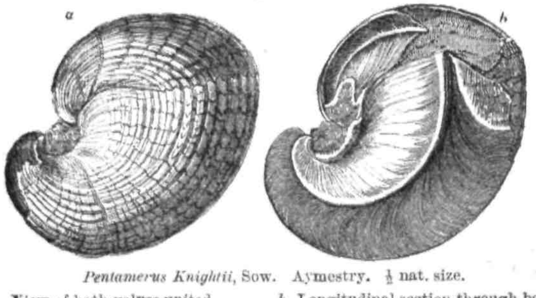


Rhynchonella navicula, Sow., nat. size, Ludlow Beds.

this bed and the Lower Ludlow. Usually in Palæozoic strata older than the Coal, the Brachiopoda greatly outnumber the lamellibranchiate mollusca. But it is remarkable that the Lamellibranchiata should outnumber the Brachiopoda in these Upper Ludlow rocks, there being 56 species of the first and only 27 of the last group. Amongst the genera are *Avicula* and *Pterinea*, *Cardiola*, *Ctenodonta* (sub-genus of *Nucula*), *Orthonota*, *Modiolopsis*, and *Palæarca*.

Some of the Upper Ludlow sandstones are ripple marked, thus affording evidence of gradual deposition; and the same

Fig. 532.



Pentamerus Knightii, Sow. Aymestry. ½ nat. size.
a. View of both valves united. *b*. Longitudinal section through both valves, showing the central plates or septa.

may be said of the accompanying fine argillaceous shales, which are of great thickness, and have been provincially named 'mud-

stones.' In some of these shales, stems of Crinoidea are found in an erect position, having evidently become fossil on the spots where they grew at the bottom of the sea. The facility with which these rocks, when exposed to the weather, are resolved into mud, proves that, notwithstanding their antiquity, they are nearly in the state in which they were first thrown down.

b. **Lower Ludlow Beds.**—The chief mass of this formation consists of a dark grey argillaceous shale with calcareous concretions, having a maximum thickness of 1,000 feet. In some places, and especially at Aymestry in Herefordshire, a subcrystalline and argillaceous limestone, sometimes 50 feet thick, overlies the shale, and appears rising above the denuded Lower Ludlow shales. It is not very continuous, so that the shales of the Lower and the strata of the Upper Ludlow come together around it. Sir R. Murchison classes this Aymestry limestone as holding an intermediate position between the Upper and Lower Ludlow. It is distinguished by the abundance of *Pentamerus Knightii*, Sow. (fig. 532), also found in the Wenlock limestone and shale. This genus of Brachiopoda is exclusively palæozoic. The name was derived from πεντε, *pente*, five, and μερος, *meros*, a part, because both valves are

Fig. 533.

Lingula Lewisii, Sow., nat. size. Abberley Hills.

Fig. 534.

Rhynchonella (*Terebratula*) *Wilsoni*, Sow., nat. size. Aymestry.

divided by a central septum, making four chambers, and in one valve the septum itself contains a small chamber, making five. The size of these septa is enormous compared with those of any other Brachiopod shell; and they must nearly have divided the animal into two equal halves; but they are, nevertheless, of the same nature as the septa or plates which are found in the interior of *Spirifera*, *Uncites*, and many other shells of this order. Messrs. Murchison and De Verneuil discovered this species dispersed in myriads, through a white limestone of Upper Silurian age, on the banks of the Is, on the eastern flank of the Urals in Russia, and a similar species is frequent in Sweden.

Three common shells in the Aymestry limestone are—*Lingula Lewisii* (fig. 533); *Rhynchonella Wilsoni*, Sow. (fig. 534),

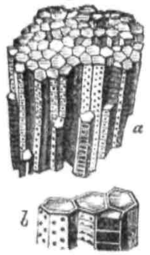
masses of grey subcrystalline limestone, replete with corals, Encrinites, and Trilobites. It is essentially of a concretionary nature; and the concretions, termed 'ball-stones' in Shropshire, are often enormous, even 80 feet in diameter. They are composed chiefly of carbonate of lime, the surrounding rock being more or less argillaceous.[2] Sometimes this limestone is oolitic. All the limestones of the Upper Silurian are in great lenticular masses, and thin out so as to have their space occupied by the shaly strata of the lower and upper divisions of the same great age.

Fig. 539.

Halysites catenularia, Linn. sp., ½. Upper and Lower Silurian.

Among the corals[3] in which this formation is so rich, 76 species being known, the 'Chain-coral,' *Halysites catenularia* (fig. 539), may be pointed out as one very easily recognised, and widely spread in Europe, ranging through all parts of the Silurian group, from the Aymestry limestone to near the bottom of the Llandeilo rocks. Another coral, the *Favosites Gothlandica* (fig. 540), is also met with in profusion, in large hemispherical masses, which break up into columnar and prismatic fragments. Another common form in

Fig. 540.



Favosites Gothlandica, Lam. Dudley.

a. Portion of a large mass; less than the natural size.
b. Magnified portion, to show the pores and the partitions in the tubes.

Fig. 541.

Omphyma turbinata, Linn. sp., ½. (*Cyathophyllum*, Goldf.)
Wenlock Limestone, Shropshire.

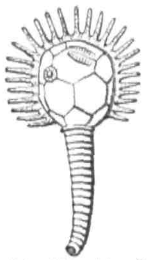
the Wenlock limestone, is the *Omphyma turbinata* (fig. 541), which, like many of its modern companions, reminds us of some

[2] Murchison's Siluria, chap. vi.
[3] Including the *Tabulata* and *Rugosa*.

cup-corals; but all the Silurian genera belong to the palæozoic type before mentioned (p. 392).

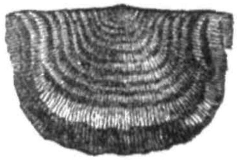
Among the numerous Crinoidea, several peculiar species of *Cyathocrinus*, *Crotalocrinus*, &c., contributed their dismembered

Fig. 542.



Pseudocrinites bifasciatus, Pearce, $\frac{2}{3}$. Wenlock Limestone, Dudley.

Fig. 543.



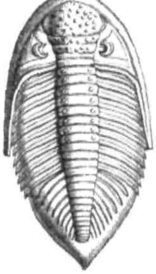
Strophomena (Leptæna) depressa, Sow., nat. size. Wenlock and Ludlow Rocks.

calcareous stems, arms, and cups towards the composition of the Wenlock limestone. Of Cystoidea there are a few very remarkable forms, most of them peculiar to the Upper Silurian formation; as, for example, the *Pseudocrinites*, which was furnished

Fig. 544.

Calymene Blumenbachii, Brong., $\frac{2}{3}$. Ludlow, Wenlock, and Bala Beds.

Fig. 545.



Phacops (Asaphus) caudatus, Brong., $\frac{1}{2}$. Wenlock and Ludlow Rocks.

Fig. 546.

Sphærexochus mirus, Beyrich, nat. size; coiled up; Wenlock Limestone, Dudley; also found in Ohio, N. America.

with pinnated fixed arms,[4] as represented in the annexed figure (fig. 542).

The Brachiopoda preponderated over most of the other groups, no less than 22 genera and 101 species being found. *Atrypa Barrandei*, *Orthis æquivalvis*, *Siphonotreta Anglica* are

[4] E. Forbes, Mem. Geol. Survey, vol. ii. p. 496.

special forms; about 11 species pass up into the Aymestry limestone. Examples are *Atrypa reticulata* and *Orthis elegantula*.

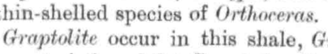
The Crustacea are represented by Eurypteridæ, which appear for the first time, including the genera *Pterygotus* and *Eurypterus*, and by Ostracoda and by Trilobites. The Trilobite *Calymene Blumenbachii* is common, and it ranges from the Llandeilo group to near the top of the Silurian. It is often found coiled up like the common Wood-louse, and this is so usual a circumstance among certain genera of Trilobites as to lead us to conclude that they must have habitually resorted to this mode of protecting themselves when alarmed. *Encrinurus punctatus*, *Sphærexochus mirus* (fig. 546), is almost globular when rolled up, the forehead or glabella of this species being extremely inflated. The other common species is the *Phacops caudatus* (fig. 545), which is conspicuous for its large size and flattened form. In the genus *Homalonotus* the tripartite division of the dorsal crust is almost lost (see fig. 547); it is characteristic of this division of the Silurian series.

Fig. 547.

Homalonotus delphinocephalus, Konig, ½. Wenlock Limestone, Dudley Castle.

Wenlock shale.—Fine grey and black shales, with most of the fossils common to the overlying limestone. In the Malvern district it is a mass of finely levigated argillaceous matter, attaining, according to Professor Phillips, a thickness of 640 feet; but it is sometimes more than 1,000 feet thick in Wales, and is worked for flagstones and slates. The prevailing fossils, besides corals and Trilobites, and some Crinoidea, are several small species of *Orthis*, *Atrypa*, and *Rhynchonella*, and numerous thin-shelled species of *Orthoceras*.

Fig. 548.



Graptolithus priodon, Bronn, nat. size. Ludlow and Wenlock Shales, and Bala group.

About six species of *Graptolite* occur in this shale, *Graptolithus Flemingii* being characteristic, whilst *G. priodon* (fig. 548) ranges through into the Ludlow group. These Hydrozoa will be considered further on.

b. Woolhope limestone underlies the Wenlock shale, and consists of grey shales, with nodular limestone. It is well seen in the valley of Woolhope, and at Malvern there is much shale beneath. The chief fossils of the Woolhope limestone are principally Crustacea, all of the Trilobite group, and Brachiopoda.

Examples of the fossils: *Phacops caudatus*, *Homalonotus delphinocephalus* (fig. 547), *Strophomena imbrex*, *Rhynchonella Wilsoni* (fig. 534), and *Eucalyptocrinus polydactylus*. This limestone is in large lenticular masses, and is overlapped at its edges by the underlying shales which then join continuously with the Wenlocks above.

There is a very persistent set of beds of fine light grey or blue shales, termed 'paste-rock,' which overlie the Upper Llandovery strata over a considerable tract of country from the Conway into Caermarthenshire, just as the Woolhope limestone covers these last-mentioned strata in Shropshire and Herefordshire. These Tarannon shales are 1,000 to 1,500 feet thick in places, and contain numerous species of *Graptolites*, corals of the genera *Favosites* and *Cyathophyllum*: one of the Crinoidea, *Actinocrinus pulcher*, which passes up into the Lower Ludlow, and the Brachiopod *Lingula Symondsii*. The Tarannon shales are covered, in Denbighshire, by grits and sandstones at least 3,000 feet thick, and which pass into hard shales of probably Wenlock age. These Denbighshire grits are in mountain ranges in North and South Wales, and produce a very sterile soil. They probably were formed during the age of the collection of the Wenlock deposits. It is interesting to note that these grits do not pass up into the base of the Old Red Sandstone, but lie unconformably below it, indicating great terrestrial movements before its deposition. This is very different to the state of things sixty miles off, where the Old Red rests conformably on the underlying Upper Silurian.

Dr. Hicks, F.G.S., found vegetable remains in the Denbighshire grits, such as the Lycopod *Pachytheca* already noticed (p. 418), and a remarkable marine Alga *Nematophycus*, which probably resembled the great branching *Lessoniæ* of the present day, in its habit. Many of these great marine Algæ of the existing ocean, measure 30 feet in length and a foot in diameter.

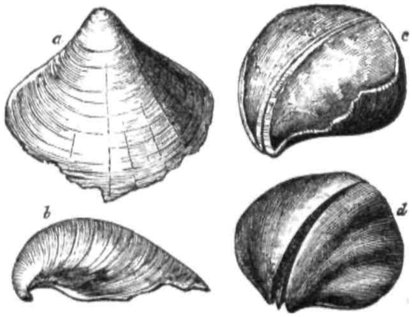
The marine fossils are sponges, *Cliona prisca* and *Spongarium Edwardsii*; corals, *Favosites aspera*, *Syringopora serpens*; there are 19 species of Brachiopoda, all common to the Wenlock limestone; Cephalopoda, genera *Orthoceras*, *Phragmoceras*, and *Cyrtoceras*.

3. **Llandovery group—Upper Llandovery rocks.**—The succession of these strata has been noticed, and it must be remembered that the Wenlock group rests conformably on the Upper Llandovery beds, which in their turn cover the worn and denuded surfaces of the disturbed, curved, and faulted underlying rocks to which they are unconformable. Upper Llandovery rocks, named May Hill Sandstones by Sedgwick after the locality

in Gloucestershire where they are so well displayed, appear on the coast of Pembroke at Marloes Bay. They range across South Wales until they are overlapped by the Old Red Sandstone, and emerge again in Caermarthenshire, and travel north-east as a narrow strip at the base of the Upper Silurian series, from a few feet to 1,000 feet or more in thickness, as far as the Longmynd, where, as a marked conglomerate, they wrap round that ancient Cambrian ridge and disappear. (Geikie.) In the course of this long tract they pass successively and unconformably over Lower Llandovery, Caradoc, Llandeilo, and Cambrian rocks. They consist of brownish and yellow sandstones with calcareous nodules, having sometimes a conglomerate at the base derived from the waste of older rocks.

The fauna of the Upper Llandovery rocks consists of 240 species, and only 91 of these do not pass up into the Wenlock group, so that the physical unconformity of the two groups is accompanied by no palæontological break of importance. The Lamellibranchiata become of importance in this fauna, and the Gasteropoda of the genera, *Holopella*, *Acroculia*, *Raphistoma*, and *Turbo* also. The Brachiopoda number in species more than double those of any other class, there being 65

Fig. 549.



Pentamerus oblongus, Sow., nat. size. Upper and Lower Llandovery beds.

a, *b*. Views of the shell itself, from figures in Murchison's 'Sil. Syst.'

c. Cast with portion of shell remaining, and with the hollow of the central septum filled with spar.

d. Internal cast of a valve, the space once occupied by the septum being represented by a hollow in which is seen a cast of the chamber within the septum.

species, including *Pentamerus oblongus* (fig. 549), *Stricklandinia lirata*, *S. lens*, *Orthis calligramma*, *O. elegantula*, *Strophomena compressa*. Amongst the corals *Favosites* and *Heliolites* are found. The first Echinoid occurs, *Palæchinus Phillipsiæ*, and its plates

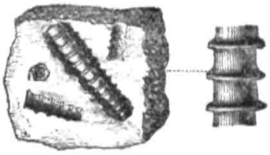
abut one against the other and do not overlap. *Tentaculites*, an Annelid, is found (fig. 551), and *Cornulites* also.

Pentamerus oblongus, accompanied by *Stricklandinia lirata*

Fig. 550.

Stricklandinia (*Pentamerus*) *lirata*, Sow., ½.

Fig. 551.

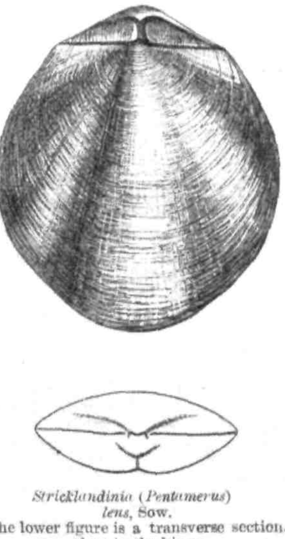


Tentaculites annulatus, Schlot. Interior casts in sandstone. Upper Llandovery, Eastnor Park, near Malvern.
Natural size and magnified.

(fig. 550), have a wide geographical range, being also met with in the same part of the Silurian series in Russia and the United States. The Trilobites are of the genera *Illænus* and *Calymene*, *Encrinurus* and *Phacops*.

Lower Llandovery Rocks.—The Upper Llandovery strata rest unconformably on the Lower, and there is a clear physical break; but the palæontological break is not of corresponding importance to it. The hard slaty rocks and conglomerates, from 600 to 1,000 feet in thickness, of the Lower Llandovery group contain a fauna of 68 genera and 204 species. Nearly one-half (104) of the species pass up into the Upper Llandovery strata. Etheridge explains that the lapse of time which occurred between the disturbance of the Lower Llandovery rocks and the deposition of the Upper, was not of sufficiently long duration to cause the extinction or migration of the older fauna or the introduction of a perfectly new one. The physical change in all probability was not very widely felt.

Fig. 552.



Stricklandinia (*Pentamerus*) *lens*, Sow.
The lower figure is a transverse section, close to the hinge.

The Brachiopoda are numerous in the Lower Llandovery rocks, and the genera *Pentamerus* and *Stricklandinia* appear for

the first time; the species with the most numerous individuals being *Stricklandinia lens* (fig. 552), *S. lirata*, and *Pentamerus oblongus*, *P. undatus*, especially the first named. The genus *Murchisonia* occurs amongst the Gasteropoda, and *Bellerophon* and the Pteropod *Conularia* have species. The Trilobites are remarkable, because no less than 18 species pass into this group of strata from lower rocks, and 10 pass upwards into the Upper Llandovery group; and this passage of forms is noticed also in the Actinozoa, but in a greater degree. The Graptolites are very rare in the English Lower Llandovery strata.

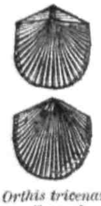
It appears that the Lower Llandovery strata, having a fauna, the half of which lived on, in the Upper Llandovery rocks, and 105 species of which are also found fossil in the underlying Caradoc or Bala strata, are occasionally unconformable to these last. The importance of this palæontological continuity, associated with unconformity, may be estimated by the fact that the underlying Caradoc formation contains 614 species, and thus one-sixth of the fauna transgress.

LOWER SILURIAN FORMATION.

This formation is divided into—1st, the Bala and Caradoc group; 2nd, the Llandeilo Flags; and, 3rd, the Arenig or Lower Llandeilo series. It corresponds with the Upper Cambrian of Sedgwick.

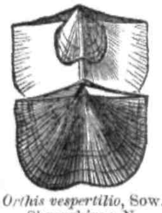
1. **The Bala and Caradoc Group.**—The Caradoc Sandstone was so named by Murchison, from Caer Caradoc in Shropshire. It consists of shelly sandstones of great thickness,

Fig. 553.



Orthis tricenaria, Conrad.
New York; Canada.
½ nat. size.

Fig. 554.



Orthis vespertilio, Sow., Shropshire; N. and S. Wales.
½ nat. size.

Fig. 555.

Strophomena grandis. Sow., ⅔ nat. size.
Caradoc Beds, Horderley, Shropshire; and Coniston, Lancashire.

sometimes containing much calcareous matter. In the Bala district there is an upper and a lower limestone, with an intermediate series of sandy and slaty strata; the lower limestone has a great extension in North Wales.

These very fossiliferous strata contain a large number of Brachiopoda, and *Strophomena grandis* (fig. 555), *S. deltoidea*, *Orthis plicata*, and *Rhynchonella nasuta* are amongst the characteristic species, whilst *Orthis vespertilio* (fig. 554) and *Orthis tricenaria* (fig. 553) are common to this group and the Llandovery. There are no less than 109 species of Brachiopoda in the group, and they outnumber the Lamellibranchiata with 76 species, as is almost always the case in the other Silurian rocks of every country. Their proportional numbers can by no means be explained by supposing them to have inhabited seas of great depth, for the contrast between the Palæozoic and the present state of things has not been essentially altered by the late discoveries made in our deep-sea dredgings. We find the living Brachiopoda so rare as to form a very small fraction of the whole bivalve fauna; whereas, in the Lower Silurian rocks, where the Brachiopoda reach their maximum, they are greatly in excess of the Lamellibranchiata.

There may, indeed, be said (with the exception already noticed) to be a continued decrease of the proportional number of Brachiopoda as we proceed from older to newer rocks.

The Gasteropoda are very numerous, and amongst the 53 species only 2 are known in lower rocks, and 10 pass upwards, so that a characteristic series of 41 species exists. They indicate, as do the Lamellibranchs, shallow-water conditions, and some of the genera are *Murchisonia*, *Holopella*, *Rhaphistoma*, and *Turbo*. Pteropoda and Heteropoda are found, and there are 47 species of Cephalopoda, of which 39 are peculiar to the groups of strata. *Lituites*, *Orthoceras*, and *Cyrtoceras* are common genera.

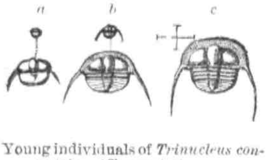
The Crustacea are the largest class in this group, and no less than 123 species of Trilobita have been discovered. Only 15 pass upwards, and amongst them are—*Calymene Blumenbachii*, *C. Caractaci*, *Encrinurus punctatus*, *Lichas loxatus*, and *Phacops caudatus*. Some of the characteristic genera are—*Harpes*, *Salteria*, and *Cyclopyge*. Some of the Trilobita found in the Caradoc group lived also in the previous period of the Llandeilo, and *Trinucleus concentricus* (fig. 557) is an example with *Calymene Blumenbachii* and *Ampyx rostratus*.

The Trilobite order of Crustacea has a great number of genera which are found in the Palæozoic rocks, beneath the Permian. It was at its maximum of numbers in the Caradoc age, and diminished rapidly in the Devonian, becoming rare and extinct in the Carboniferous formation. The trilobed body, with a cephalic or head-shield bearing a pair of eyes, with body rings and a hinder shield or pygidium, are well seen in most of the order. Some have the angles of the cephalic

shield produced (fig. 557), and Woodward has described the mouth, which has an upper lip, a maxilla, and a palpus, or 'feeler.'

In 1870 Mr. Billings suspected, from the appearance of a specimen found in Canada, that the Trilobite was provided with

Fig. 556.



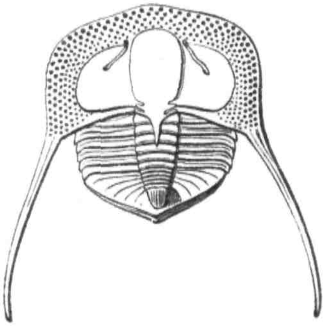
Young individuals of *Trinucleus concentricus* (*T. ornatus*).

a. Youngest state. Natural size and magnified; the body rings not at all developed.

b. A little older. One thorax joint.

c. Still more advanced. Three thorax joints. The fourth, fifth, and sixth segments are successively produced, probably each time the animal moulted its crust.

Fig. 55.



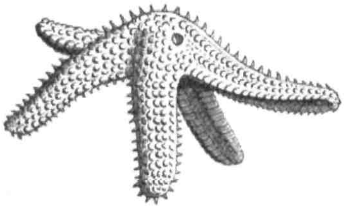
Trinucleus concentricus, Eaton.
Syn. *T. Caractaci*, Murch., nat. size.
Ireland; Wales; Shropshire; N. America; Bohemia.

eight legs; it appears, after the researches of Walcott, that the semi-calcified arches in the membrane of the ventral surface of the body support a row of jointed appendages on either side of the middle line, like two sets of jointed legs with a claw. Moreover, the base of each leg appears to carry another and smaller jointed process. On either side of the body and outside the 'legs' are bifid, spiral, gill-looking bodies. An *Asaphus*, according to Mickleborough and Walcott, has 26 pairs of appendages—9 beneath the thorax, 1 beneath the head, and 16 beneath the pygidium. The appendages show seven joints in two instances. Numerous small filaments represent the spiral filaments of *Calymene*. Billings decided that an *Asaphus* had a pair of appendages to each segment of the thorax, and none on the abdomen proper. The head-shield is made up of a cerebral part or glabella, and of two side portions, and there is a suture—the facial—between these and the glabella, close to a surface called the fixed cheek. The eyes, crescent-shaped, or reniform, have a number of facets upon them, and are wanting in some genera, *Agnostus*, *Ampyx*, and some *Trinuclei* (fig. 557), for instance, and in some species of genera which have forms with eyes also. Some genera have mouth and eyes. Trilobites underwent metamorphosis, and Barrande traced more than twenty species

through different stages of growth from the young state, just after its escape from the egg, to the adult form. He has followed some of them from a point in which they show no eyes, no joints, or body rings, and no distinct tail, up to the complete form with the full number of segments. This change is brought about before the animal has attained a tenth part of its full dimensions, and hence such minute and delicate specimens are rarely met with. Some of his figures of the metamorphoses of the common *Trinucleus* are copied (figs. 556, *a–c*).

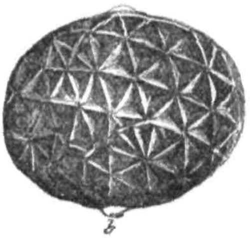
The Rugose Corals, the Alcyonaria and Hydrocorallinæ, were well represented, *Cyathophyllum*, *Heliolites*, and *Halysites* being common genera. The Echinodermata were represented

Fig. 558.



Palæaster asperimus, Salt.
Caradoc, Welshpool.

Fig. 559.



Echinosphærites balticus, Eichwald, nat. size. (Of the family *Cystoidea*.)
a. Mouth.
b. Point of attachment of stem.
Lower Silurian, S. and N. Wales.

by the Cystoidea (fig. 559), and 23 species are characteristic; one also (*Echinospherites arachnoidea*) passes up into the Llandovery group. The Cystoidea (fig. 142) were stalked as a rule, and became extinct during the Devonian age. It is interesting to note that the *Blastoidea*, of which *Pentremites* is a well-known Carboniferous genus, began to flourish when the Cystoidea began to seriously diminish in numbers, and gained their maximum development during the Carboniferous age. All were Palæozoic. Crinoidea existed in the Caradoc age, and also Asteroidea of the genera *Palæaster* (fig. 558) and *Stenaster*.

About 38 species of Graptolites occur, and 16 of these came from lower rocks; they are chiefly found in peculiar localities where black mud abounded. The formation, when traced into South Wales and Ireland, assumes a greatly altered mineral aspect, but still retains its characteristic fossils. The known fauna of the Caradoc and Bala group comprises 614 species, 375 of which are peculiar, and 105 pass up to the overlying Llandovery

rocks; 73 species came from the Llandeilo group below. It is worthy of remark that when these strata occur under the form of trappean tuff (volcanic ashes of De la Beche), as in the crest of Snowdon, the peculiar species which distinguish it from the Llandeilo beds are still observable. The formation generally appears to be of shallow-water origin, and in that respect is contrasted with the group next to be described. Sir A. Ramsay estimates the thickness of the Bala beds, including the contemporaneous volcanic rocks, stratified and unstratified, as being from 10,000 to 12,000 feet.

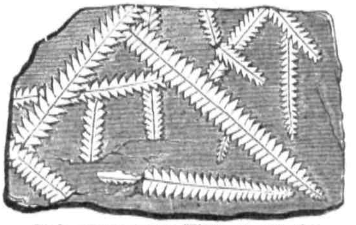
2. **Llandeilo Group.**—These strata at Llandeilo, a town in Caermarthenshire, consist of dark-coloured argillaceous and micaceous flags, frequently calcareous, with a great thickness of shales, generally black, below them. They are also seen at Abereiddy Bay in Pembrokeshire and at Builth in Radnorshire, where they are interstratified with volcanic matter. They are conformable with the overlying Caradoc group.

A still lower part of the Llandeilo rocks consists of a black carbonaceous slate of great thickness, frequently containing

Fig. 560.

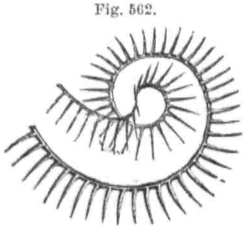
Didymograptus Murchisonii, Beck, ½.
Llandeilo flags, Wales.

Fig. 561.



Diplograptus pristis, Hisinger, nat. size.
Llandeilo beds, Waterford.

Fig. 562.



Rastrites peregrinus, Barrande, nat. size.
Scotland; Bohemia; Saxony; Llandeilo flags.

Fig. 563.

Diplograptus folium, Hisinger.
Phyllograptus.
Dumfriesshire; Sweden.
Llandeilo flags.

sulphide of iron, and sometimes, as in Dumfriesshire, beds of anthracite. It has been conjectured that this carbonaceous matter may be due in great measure to large quantities of embedded animal remains, for the number of Graptolites included in these slates is certainly very great. In North and South

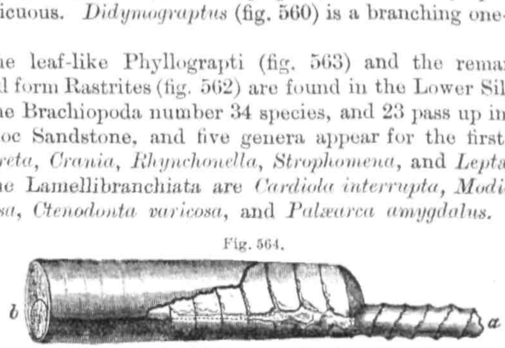
Wales 25 species of Graptolites occur in the Llandeilo flags. The double Graptolites, or those with two rows of cells, such as *Diplograptus* (fig. 561), *Climacograptus*, and *Dicranograptus*, are conspicuous. *Didymograptus* (fig. 560) is a branching one-celled form.

The leaf-like Phyllograpti (fig. 563) and the remarkable curved form Rastrites (fig. 562) are found in the Lower Silurian.

The Brachiopoda number 34 species, and 23 pass up into the Caradoc Sandstone, and five genera appear for the first time, *Acrotreta*, *Crania*, *Rhynchonella*, *Strophomena*, and *Leptæna*.

The Lamellibranchiata are *Cardiola interrupta*, *Modiolopsis expansa*, *Ctenodonta varicosa*, and *Palæarca amygdalus*. Some

Fig. 564.

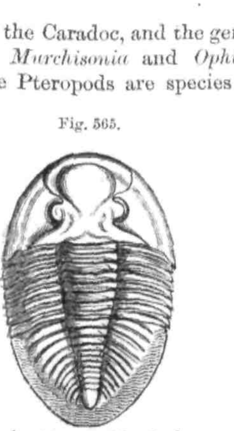


Orthoceras duplex, Wahlenberg. Russia and Sweden. (From Murchison's 'Siluria.')

a, Lateral siphuncle laid bare by the removal of a portion of the chambered shell.
b, Continuation of the same seen in a transverse section of the shell.

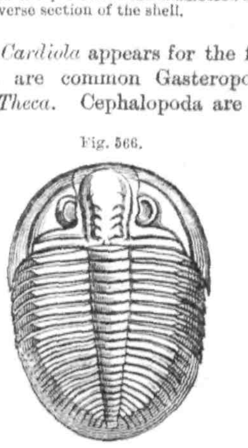
pass to the Caradoc, and the genus *Cardiola* appears for the first time. *Murchisonia* and *Ophileta* are common Gasteropoda, and the Pteropods are species of *Theca*. Cephalopoda are not

Fig. 565.



Asaphus tyrannus, Murch., ⅓. Llandeilo; Bishop's Castle, &c.

Fig. 566.



Ogygia Buchii, Burm., ⅓. Syn. *Asaphus Buchii*, Brongn. Builth, Radnorshire; Llandeilo, Caermarthenshire.

common in the British Llandeilo formation; but *Orthoceras*, *Endoceras*, and *Piloceras* are usual genera. On the Continent of Europe the Orthoceratidæ are very common (fig. 564).

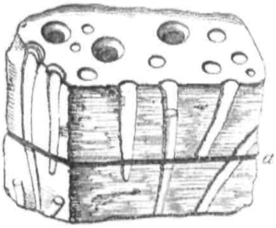
The genera *Asaphus* (fig. 565), *Ogygia* (fig. 566), and *Trinu-*

cleus form a marked feature of the Trilobite fauna of this age, which comprehends 18 genera and 45 species.

There are about 80 genera and 175 species of fossils in this group, and 38 genera and 73 species pass up to the Caradoc group.

3. **Arenig or Stiper-stones group.**—Next in the descending order, and forming the base of the Lower Silurian, are the shales and sandstones in which the quartzose rocks called Stiper-stones in Shropshire occur. For a long time the only organic remains in these Stiper-stones were the tubular burrows of annelids (see fig. 567, *Arenicolites linearis*), which are remarkably common in the Lowest Silurian in Shropshire, the North-west Highlands of Scotland, and in the State of New York in America. I have seen similar burrows now made on the retiring of the tides in the sands of the Bristol Channel, near Minehead, by lobworms, which are dug out by fishermen and used as bait.

Fig. 567.



Arenicolites linearis, Hall.
Arenig beds. Stiper-stones.
a. Parting between the beds, or planes of bedding.

Sedgwick recognised this group, which he called the Arenig or Skiddaw, and separated it from the overlying and conformable Llandeilo. Salter, however, distinguished the great biological break between the Arenig and the underlying Tremadoc group, and Dr. Hicks has defined the succession in South Wales, and described a great fauna in the Arenigs of the St. David's district. It must be understood that there is no stratigraphical unconformity between the Arenig and the groups above and below it. But the palæontological break is considerable, for out of the 150 species of fossils of the Arenig strata only 25 have been found above and below them. Only 8 genera comprising 9 species pass from the Arenigs to the Llandeilo above, and 11 genera comprising 46 species came into the Arenig area which had lived in Tremadoc times. No less than 40 genera appear for the first time in the Arenig group, and this in itself gives a definite importance to it. Of these there are 16 genera of the Hydrozoa of the Graptolite group. *Didymograptus* (fig. 568), *Callograptus*, *Diplograptus*, and *Tetragraptus* are examples. Four genera of Annelida, *Helminotholithes*, *Stellascolithes*, *Nereites*, and *Palæochorda*, appeared; and the genera of the Trilobita, *Æglina*, *Trinucleus*, *Barrandia*, *Calymene*, *Phacops*, *Placoparia*, *Illænus*, and *Homalonotus*. *Ribeiria* and *Redonia* were new Lamellibranchs, and *Ophileta*,

Pleurotomaria, *Rhaphistoma*, new genera of Gasteropoda. *Orthoceras* occurs, and there are four species of it in the Welsh and

Fig. 568.

Didymograptus geminus, Hisinger, sp. Sweden.

Shropshire area. The corals, Bryozoa and Echinodermata are not represented. Phyllopoda of the genus *Caryocaris* are peculiar to the group, and there are only 18 species of Brachiopoda, and the special forms are *Dinobolus Hicksii*, *Siphonotreta micula*, *Discina* sp., *Orthis striatula*, *O. remota*, and *O. alata*.

This Arenig group may therefore be conveniently regarded as the base of the great Silurian system—a system which, by the thickness of its strata and the changes in animal life of which it contains the record, is more than equal in value to the Devonian, or Carboniferous, or other principal divisions, whether of primary or secondary date. The name Ordovician was proposed by Professor Lapworth, for strata included between the base of the Lower Llandovery formation and that of the Lower Arenig. But the amount of palæontological continuity between the two Llandovery groups appears to militate against this proposal.

It would be unsafe, in attempting to classify, to rely on the mere thickness of the strata, considered apart from the great fluctuations in organic life which took place between the era of the Arenig and that of the Ludlow formation, especially as the enormous pile of Silurian rocks observed in Great Britain (in Wales more particularly) is derived in great part from igneous action, and is not confined to the ordinary deposition of sediment from rivers or the waste of cliffs.

Sedgwick noticed that the Arenig dark slates, shales, flags, and bands of sandstone were associated with masses of igneous rock, and it is evident that whilst the sedimentary strata were accumulating, volcanic action was progressing. Hence great thicknesses of felsatic and rhyolitic lavas and tuffs[5] were erupted and spread over the country and sea-floor, and were interstratified with the fossiliferous sediments. Geikie notices that some of the most important Welsh mountains consist mainly of these volcanic materials—namely, Cader Idris, the Arans, Arenig Mountains, and others.

In the neighbourhood of volcanic islands, such as Sicily and Java, we see, at the present time, the most active of all known

[5] See Appendix.

causes, aqueous and igneous, simultaneously at work to produce great results in a comparatively moderate lapse of time. The outpouring of repeated streams of lava—the showering down upon land and sea of volcanic ashes—the sweeping seaward of loose sand and cinders, or of rocks ground down to pebbles and sand, by rivers and torrents descending steeply inclined channels—the undermining and eating away of long lines of sea-cliff exposed to the swell of a deep and open ocean—these operations combine to produce a considerable volume of superimposed matter, without there being time for any extensive change of species. Nevertheless, there would seem to be a limit to the thickness of stony masses formed even under such favourable circumstances, for the analogy of tertiary volcanic regions lends no countenance to the notion that sedimentary and igneous rocks, 25,000, much less 45,000 feet thick, like those of Wales, could originate while one and the same fauna should continue to people the earth. If, then, we allow that about 25,000 feet of matter may be ascribed to one system, such as the Silurian, as above described, we may be prepared to discover in the next series of subjacent rocks a distinct assemblage of species, or even in great part of genera, of organic remains. Such appears to be the fact; and I shall therefore conclude my enumeration of the Silurian formations in Great Britain with the Arenig beds.

The Silurian rocks of the Lake District differ considerably in their lithology, from those of the Welsh and adjoining English areas; but the groups of strata of these different localities can be associated in a classification founded principally upon palæontological data. Mr. Marr,[6] following Nicholson and Harkness, considers that the following are the probable equivalents: The Upper Ludlow is represented in the Lake District by the Kirkby Moor flags, and the Lower Ludlow and Upper Wenlock by the Bannisdale slates. The rest of the Wenlock is equivalent to the Coniston grits, Coldwell beds, and Brathay flags. The Tarannon shales are the same as the Pale shales. Some Graptolitic mudstones with *Monograptus* appear in the Welsh and Lake areas. The Llandovery group are probably represented by some of the Coniston mudstones, and, according to Professor Hughes, by the Anstwick conglomerates (?).

The Bala and Caradoc probably accumulated during the period of the Asgill shales, Coniston limestone, and the underlying great volcanic series, the Borrowdale. The Arenigs are the equivalents of the Skiddaw slates.

The Silurian strata of the Southern Highlands consist of

[6] Quart. Journ. Geol. Soc. vol. xxxvi. p. 278.

greatly contorted strata, which have been worn and denuded into hills of moderate height, and deep valleys. In the Girvan district there are, besides conglomerates and metamorphosed rocks, calcareous beds, which represent the Llandovery, Bala, and Llandeilo groups. In the Moffat district there are gritty, or coarse-grained greywacke, fissile flagstones, conglomerates, and bands of black carbonaceous shales, with cream-coloured clay and iron nodules. These black bands are in lenticular masses in the greywacke, and, although they cover a vast area, are contorted, often reversed, and highly fossiliferous. Lapworth has shown that there are three horizons of these black bands, which contain a profusion of Graptolites. The highest, or Lower Llandovery—the Birkhill shales, contain zones of *Rastrites*, *Monograptus*, and *Diplograptus*, and there is a decided palæontological break between this horizon and the next below, or the Hartfell shales, which are of Bala age, and contain *Dicellograptus*, *Pleurograptus*, and *Climacograptus*. The Glenkiln shales are upper Llandeilo in age, and contain *Didymograptus*. They are the lowest Silurian rocks in this part of Scotland. Geikie notices that in the counties of Edinburgh and Lanark, the Old Red covers shales of brown and yellow colour with fossils of Ludlow age, and probably their lower portions are of the Wenlock period. In the north-west of Scotland the Assynt limestone contains fossils which give it an Arenig age.

European Silurian strata. — Silurian strata cover vast areas in Europe, and they vary much in thickness. The thinning out appears to be from the Welsh area to the north-east; and the Silurians of South Scandinavia are only 1,200 feet thick, and but slightly disturbed. All the groups, including those above and below the Llandovery, with *Pentamerus*, are present. The schists and flagstones below are of Caradoc age, some Llandovery fossils, however, being found in them; moreover, *Pentamerus oblongus* reaches up into the Wenlock. A Graptolite-bearing series, with the Trilobites *Asaphus* and *Trinucleus*, covers Ceratopyge-Kalk with *Orthoceras duplex* and *O. annulatum*, and belongs to the Llandeilo. The Arenigs are represented by Lower Graptolite schists, and these rest upon Alum schists.

In Russia the Silurian strata cover vast districts between the Baltic and the Ural Mountains, and, except near these hills, they are horizontal, unaltered, and shallow. The groups of the Upper Silurian are present, and the Llandovery (*Pentamerus*) rocks are at the base. They cover the Caradoc series, and Llandeilo of the Lower Silurian, Arenigs being at the base. A limestone full of glauconite grains underlies the Orthoceratite limestone of the Llandeilo, and rests on a glauconite sand, with

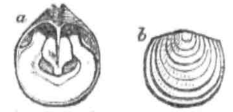
Foraminifera of the genera *Panderella*, *Cymbulia*, and with *Conodonts*.

Shells of the lowest known Fossiliferous Beds in Russia.

Fig. 569.

Siphonotreta unguiculata, Eichwald, nat. size.
From the lowest Silurian Sandstone, 'Obolus grits,' of Petersburg.
a. Outside of perforated valve.
b. Interior of same, showing the termination of the foramen within. (Davidson.)

Fig. 570.



Obolus Apollinis, Eichwald, nat. size.
From the same locality.
a. Interior of the large or ventral valve.
b. Exterior of the upper (dorsal) valve. (Davidson, 'Palæontograph. Monog.')

M. Joachim Barrande, after many years' exploration of Bohemia, and after describing a vast number of species of fossils, had ascertained the existence in that country of three distinct faunas below the Devonian. To his first fauna he gave the name of Étage C; his two first stages A and B consisting of crystalline and metamorphic rocks and unfossiliferous schists. This Étage C or primordial zone proved to be the equivalent of the Upper Cambrian, to be described in the next chapter. The second fauna, Étage D, tallies with the Lower Silurian as defined by me. The third fauna, Étages E, F, G, agrees with the Upper Silurian of Murchison.

Caradoc and Llandeilo strata are found in France and Belgium, and Lower and Upper Silurians are placed here and there in Germany. Orthoceras has been found in the Eastern Alps.

Silurian Strata of the United States.—The Silurian formations can be advantageously studied in the States of New York, Ohio, and other regions north and south of the great Canadian lakes. Here they are often found, as in Russia, nearly in horizontal position, and are more rich in well-preserved fossils than in almost any spot in Europe. In the State of New York, the subdivisions given in the first column of the annexed list have been adopted.

American Strata.—British Equivalents.

Oriskany formation.	Oriskany Sandstone	Upper Silurian (Ludlow)
Lower Helderberg.	Upper Pentamerus Limestone Delthyris Shaly Limestone Pentamerus and Tentaculite Limestones Water Lime Group	
Salina.	Onondaga Salt Group	

Niagara.	Niagara Group	Wenlock.
	Clinton Group	Upper Llandovery Group.
	Medina Sandstone, with Oneida Conglomerate	
Trenton.	Hudson River Group	Lower Silurian or Caradoc and Bala, Llandeilo and Arenig Formations.
	Utica Group	
	Trenton Group	
Canadian.	Chazy Group	
	Quebec Group	
	Calciferous Group	

That the Niagara Limestone, over which the river of that name is precipitated at the great cataract, together with its underlying shales, corresponds to the Wenlock limestone and shale of England, there can be no doubt. Among the species common to this formation in America and Europe are *Calymene, Blumenbachii*, *Homalonotus delphinocephalus*, with several other trilobites; *Rhynchonella Wilsoni*, and *Retzia cuneata*, *Orthis elegantula*, *Pentamerus galeatus*, with many more brachiopods; *Orthoceras annulatum*, amongst the cephalopods; and *Favosites Gothlandica*, with other large corals.

The Clinton Group, containing *Pentamerus oblongus* and *Stricklandinia*, is the equivalent of the Llandovery Group or beds of passage.

The Hudson River Group, and the Trenton Limestone, agree palæontologically with the Caradoc or Bala Group, containing in common with them several species of trilobites, such as *Asaphus* (*Isotelus*) *gigas*, *Trinucleus concentricus* (fig. 557); and various shells, such as *Orthis striatula*, *Orthis biforata* (or *O. lynx*), *O. porcata* (*O. occidentalis* of Hall), and *Bellerophon bilobatus*. In the Trenton Limestone occurs *Murchisonia gracilis* (fig. 571), a fossil also common to the Llandeilo beds in England.

Fig. 571.

Murchisonia gracilis, Hall. Nat. size.
A fossil characteristic of the Trenton Limestone.

In Canada, as in the State of New York, the Cambrian-Potsdam Sandstone underlies the above-mentioned calcareous rocks, but contains a different suite of fossils, as will be hereafter explained. In parts of the globe still more remote from Europe the Silurian strata have also been recognised, as in South America, Australia, and India. In all these regions the facies of the fauna, or the types of organic life, enable us to recognise the equivalency of the widely distributed rocks; many species are common to all these localities, but most are distinct, showing that the old notion of an universal diffusion throughout the 'primæval seas' of one uniform specific

fauna is unfounded, geographical provinces having existed in the oldest and in the most modern times.

Colonies.—M. Barrande, a very distinguished palæontologist, noticed, many years ago, that groups of fossils belonging normally to higher and later strata were intercalated amongst strata containing older forms of living things. He called these precursory collections 'Colonies,' and defined the phenomena as consisting in the partial co-existence of two faunas, which were nevertheless successive. Thus he supposed that, during the later stages of his second Silurian fauna in Bohemia, the first phases of the third fauna had already appeared, and attained some degree of development in some neighbouring but yet unknown region. He supposed that at intervals which corresponded with changes in the physical geography of a considerable area due to upheaval or subsidence, &c., communication was opened between that outer region and Bohemia. During these intervals, a greater or less number of immigrants succeeded in making their way into the Bohemian area, but as the conditions for their lasting there were not yet favourable, they soon died out, and the normal fauna of the region spread over the invaded area, but on a higher horizon. After other changes had taken place and the prevailing fauna had diminished or died off, an invasion from the distant region was followed by the full development of the parent stock (or rather of its descendants), parts of which had long before migrated without results. A remarkable instance of a so-called 'Colony' was given in explaining the affinities of the lowest Tertiaries of Belgium. Barrande's explanation may be accepted in the case of the Belgian strata; but geologists have hesitated to believe the theory in other instances, and have attributed the phenomena to the inversion of strata. But M. Barrande insists that there are no such inversions in the typical region which he studied, and indeed, from what we now know about the existence of differing neighbouring faunas being only separated by narrow tracts of land, the theory is not unreasonable. Nevertheless, the examples are rare, for in the vast majority of instances the normal succession of characteristic fossils prevails. The instance of the existence of *Serpula* and *Conularia*, Carboniferous forms, in the upper Old Red of South Wales and Shropshire is that of a Colony; but that finding of Silurian marine fossils in the Old Red (already noticed, p. 419), would not be a discovery of a Colony in Barrande's sense.

CHAPTER XXVIII.

CAMBRIAN, PRE-CAMBRIAN, AND LAURENTIAN FORMATIONS.

Classification of the Cambrian group—Upper Cambrian rocks—Tremadoc slates and their fossils—Lingula flags—Lower Cambrian rocks—Menevian beds—Longmynd group—Harlech grits, with large Trilobites—Llanberis slates—The succession in the North-west Highlands—Cambrian rocks of Bohemia—*Primordial zone of Barrande*—*Metamorphosis* of Trilobites—Cambrian rocks of Sweden and Norway—Cambrian rocks of the United States and Canada—Potsdam sandstone—Pre-Cambrian series—English and Welsh Pre-Cambrians—Canadian, Huronian series—Laurentian group, upper and lower—*Eozoon Canadense*, oldest known fossil—Fundamental gneiss of Scotland—Other gneissic areas—Archæan and Azoic series.

CAMBRIAN FORMATION.

THE Arenig group is separated from the underlying and conformable Tremadoc strata by a fairly marked palæontological break, and the strata of this last group are placed at the top of the Cambrian formation. The following is the succession of the Cambrian strata:—

UPPER CAMBRIAN.

TREMADOC SLATES. (*Primordial of Barrande in part.*)

LINGULA FLAGS. (*Primordial of Barrande.*)

LOWER CAMBRIAN.

MENEVIAN BEDS. (*Primordial of Barrande.*)

LONGMYND GROUP { *a.* Harlech Grits. *b.* Llanberis Slates.

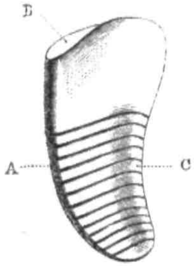
UPPER CAMBRIAN.

Tremadoc Slates.—The Tremadoc slates of Sedgwick are more than 1,000 feet in thickness, and consist of dark earthy grey slates occurring near the little town of Tremadoc, situated on the north side of Cardigan Bay in Caernarvonshire.

They were traced subsequently to Dolgelly, and of late years strata of the same age have been discovered and carefully examined by Dr. Hicks, at St. David's promontory and Ramsey Island, South Wales, where there are dark earthy flags and sandstones 1,000 feet thick, with many fossils. They rest conformably upon thick Lingula flags. Subsequently Mr.

Callaway has shown that the Shineton shale of Shropshire is of Lower Tremadoc age. The fauna is very remarkable, and differs in North and South Wales considerably, numbering at least 84 species, and many great groups of the invertebrata appear in the rocks for the first time. The Crinoidea, Asteroidea, Cephalopoda, and Lamellibranchiata are represented therein, for the first time in the world's history. There are many new genera of Trilobita, such as *Nesuretus*, *Psilocephalus*, *Niobe*, *Angelina*, *Asaphus*, and *Cheirurus*, besides some which existed in the lower rocks, such as *Agnostus*, *Conocoryphe*, and *Olenus*. The Crinoid *Dendrocrinus* and Asteroid *Palæasterina*, the Cephalopoda *Orthoceras sericeum* and *Cyrtoceras præcox* are of the Upper Tremadocs, and

Fig. 572.



Cyrtoceras precox, Salt. mag.
Llandeilo and Tremadoc rocks, N. Wales.
a. Dorsal edge, place of siphuncle.
b. Aperture. *c*. Ventral edge.

Fig. 573.

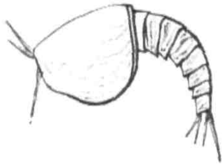
Theca (*Cleidotheca*) *operculata*, nat. size.
Lower Tremadoc beds, Tremadoc.

the Lamellibranchs *Ctenodonta*, *Palæarca*, *Glyptarca*, *Davidia*, and *Modiolopsis* are the first known. The Brachiopoda belong to the genera which existed in the underlying strata, and the species *Lingulella Davisii* and *Orthis Carausii*, and the genera *Obolella* and *Lingula*, are common to both groups. The North Wales Tremadocs contain 9 species of Pteropoda, of the genus *Theca* principally ; and *Bellerophon* is found amongst the Heteropoda. The earliest Rhabdophora were discovered, in Tremadoc rocks, by Callaway, and belong to the genus *Bryograptus*. Phyllopod Crustacea exist in the Upper Tremadocs, and the characteristic Trilobita are *Angelina Sedgwickii*, *Conocoryphe olenoides*, and *Olenus impar*. *Dictyonema sociale* and Bryozoa occur, and in the strata below also.

Lingula Flags.—Next below the Tremadoc slates in North Wales, lie micaceous flagstones, bluish and black slates and flags, with bands of grey flags and sandstones, in which in 1846 Mr.

E. Davis discovered the *Lingulella* (fig. 575) named after him, and from which was derived the name of Lingula flags. These beds are more than 5,000 feet thick, and have been studied chiefly in the neighbourhood of Dolgelly, Ffestiniog, and Portmadoc in North Wales, and also at St. David's in South Wales. They have yielded 26 genera and 69 species of fossils, of which 9 only are common to the overlying Tremadoc rocks. They are *Dictyonema sociale*, *Agnostus princeps*, *Ampyx prænuntius*, *Conocoryphe depressa*, *Olenus impar* (?), *Lingulella Davisii*, *L.*

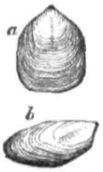
Fig. 574.



Hymenocaris vermicauda, Salter.

A Phyllopod Crustacean. ½ natural size.

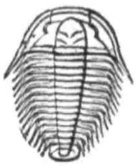
Fig. 575.



Lingulella Davisii, M'Coy.

a. ½ natural size.
b. Distorted by cleavage.

Fig. 576.



Olenus micrurus, Salter.

½ natural size.

'Lingula Flags' of Dolgelly, and Ffestiniog, N. Wales.

lepis, *Obolella*, and *Orthis*. In the Lingula flags *Olenus* (fig. 576), *Agnostus*, *Anopolenus*, *Microdiscus*, *Paradoxides*, and *Conocoryphe* are prominent forms of Trilobita, and *Hymenocaris vermicauda* (fig. 574), is a common species of Phyllopod Crustacea.

The Lingula Flags may be divided into two zones, an upper and lower, the old middle zone being of no value, and amongst the fossils of the upper zone is *Dictyonema sociale*, which occurs in the dark shales of Keys End Hill, Malvern, and in North Wales. Two genera of Annelida are also found in the Holybush Sandstone of Malvern, at the base of the Upper Lingula Flags. No less than 30 species of Crustacea belonging to the genera of Trilobita, just noticed, occur, and only 4 pass up into the Tremadocs. The Brachiopoda are of 8 species, 6 of which pass upwards, and the genera are *Lingula*, *Lingulella*, *Obolella*, *Kutorgina*, and *Orthis*, the two characteristic species being *Lingula pygmæa* and *Obolella Salteri*. In the Lower Lingula Flags, which rest conformably on the Menevian strata, *Cruziana*, a supposed Annelid, occurs, and *Scolioderma* and *Helminthites* are characteristic worms. Nine genera and 25 species of Crustacea are found. *Agnostus limbatus* and *A. nodosus*, *Olenus cataractes*, *O. micrurus*, *O. gibbosus*, are peculiar to these lower Flags, and so is the Phyllopod *Hymenocaris vermicauda*. The three genera of Brachiopoda are *Lingulella*, *Orthis*,

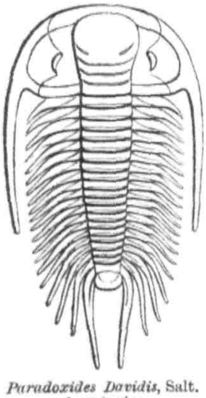
and *Obolella*. Finally, two species of *Theca* occur. It will be observed how many great groups of invertebrata are not represented, they not having yet appeared.

In Merionethshire, according to Sir A. Ramsay, the Lingula Flags attain their greatest development; in Caernarvonshire, they thin out so as to have lost two-thirds of their thickness in eleven miles; while in Anglesea and on the Menai Straits, both they and the Tremadoc beds are entirely absent, and the Lower Silurian rocks rest directly on Lower Cambrian strata.

LOWER CAMBRIAN.

Menevian Beds.—Immediately beneath the Lingula Flags there occurs a series of dark-grey and black flags and slates, alternating at the upper part with some beds of sandstone, the whole reaching a thickness of from 500 to 600 feet. These beds were formerly classed, on purely lithological grounds, as the base of the Lingula Flags; but Messrs. Hicks, Salter, and Etheridge, to whose exertions we owe almost all our knowledge of them, have pointed out that the most characteristic genera found in them are unknown in the Lingula Flags, while they possess many forms from the underlying Longmynd Group. They therefore proposed to place these beds, and it seems to me with reason, at the top of the Lower Cambrian under the term 'Menevian,' Menevia being the classical name of St. David's. The beds are well exhibited in the neighbourhood of St. David's in South Wales, and near Dolgelly and Maentwrog in North Wales. They are the equivalents of Étage C of Barrande's Primordial Zone. Fifty-two species have been found in the Menevians, which are very rich in fossils for so early a period. Nineteen species are common to the overlying Lingula Flags, but none pass up to the Tremadoc beds. Twelve genera and 32 species of Trilobita occur, and some forms are of large size; *Paradoxides Davidis* (see fig. 577), the largest Trilobite known in Great Britain, 22 inches or nearly 2 feet long, is peculiar to the Menevian, and the gigantic *P. aurora* also. The other genera are *Agnostus*, *Anopolenus*, *Conocoryphe*, *Holocepha-*

Fig. 577.



Paradoxides Davidis, Salt. $\frac{1}{10}$ nat. size. Menevian beds, St. David's and Dolgelly.

lina; and the special genera of Trilobita are *Arionellus*, *Erinnys*, *Microdiscus*, and *Carausia*.

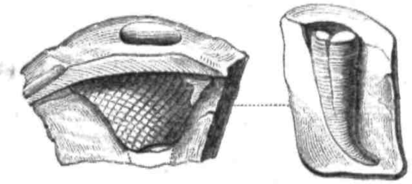
The Trilobite with the largest number of rings, *Erinnys venulosa*, occurs here in conjunction with *Agnostus* and *Microdiscus*, the two genera with the smallest number. Blind Trilobites are also found, as well as those which have the largest eyes, such as *Microdiscus* on the one hand, and *Anopolenus* on the other. *Olenus* did not then exist.

The Ostracod *Leperditia* occurs, and the genera *Orthis*, *Discina*, and *Obolella* amongst the Brachiopoda. Several Pteropoda have been found, and the first traces of Cystoidean Echinodermata in *Protocystites*. Several species of *Protospongia* of the Spongida, and *Arenicolites*, and *Serpulites* amongst the Annelida conclude the fauna. The discovery and description of this remarkable assemblage of early forms, we owe to the careful labour of Dr. Hicks.

Longmynd Group.—Older than the Menevian beds, and conformable to them, are a thick series of olive green, purple, red and grey grits and conglomerates found in North and South Wales, Shropshire, and parts of Ireland and Scotland. They have been called by Professor Sedgwick the Longmynd or Bangor Group, comprising, first, the Harlech and Barmouth grits and sandstones; and secondly, the Llanberis slates.

Harlech grits and Llanberis slates.—The sandstones of this period attain in the Longmynd Hills a thickness of no less

Fig. 578.



Histioderma Hibernica (Kin.). Oldhamia beds. Bray Head, Ireland.

1. Showing opening of burrow, and tube with wrinklings or crossing ridges, probably produced by a tentacled sea worm or annelid.
2. Lower and curved extremity of tube with five transverse lines.

than 6,000 feet without any interposition of volcanic matter; in some places in Merionethshire they are still thicker. Until recently these rocks possessed but a very scanty fauna.

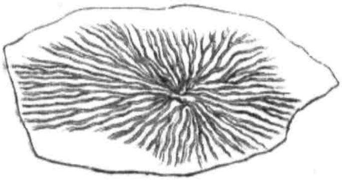
With the exception of five species of Annelids brought to light by Mr. Salter in Shropshire, and Dr. Kinahan in Wicklow, and an obscure form of Crustacean, *Palæopyge Ramsayi*,

these rocks were supposed to be barren of organic remains. Now, however, through the labours of Dr. Hicks, they have yielded at St. David's a rich fauna of Trilobita, Brachiopoda, Phyllopoda, and Pteropoda, showing, together with other fossils, the existence of a by no means low series of organisms at this very early period. Already the fauna amounts to 29 species, referred to 16 genera ; of these 8 genera and 12 species are common to the Menevian Group above ; 'a proportion,' says Dr. Hicks, 'far greater than we usually find between two groups so dissimilar in lithological characters and comprising so great a thickness of strata.'

It is one of the many proofs that the early forms of life were less influenced by the struggle for existence, which became severer with time.

A new Trilobite, called *Plutonia Sedgwickii* by Dr. Hicks, has been met with in the Harlech grits of St. David's. It is comparable in size to the large *Paradoxides Davidis* before mentioned, has well-developed eyes, and is covered all over with rough tubercles. In the same strata occur other genera of Trilobites, namely, *Conocoryphe*, *Paradoxides*, *Microdiscus*, *Agnostus*, and the Pteropod *Theca* (fig. 573), all represented by species peculiar to the Harlech grits of that area. The sandstones of this formation are often rippled, and were evidently left dry at low tides, so that the surface was dried by the sun and made to shrink and present sun-cracks. There are also distinct impressions of raindrops on the surfaces of many strata. Fossils occur yet earlier in the Harlech group of St. David's in the lower Red Shales that immediately overlie the conglomerate at the base of the Cambrian formation. The only forms yet found, are *Lingulella ferruginea*, *L. primæva*, *Leperditia Cambrensis*, and *Discina Caerfaiensis*. These, with some Annelida, constitute the earliest

Fig. 579.



Oldhamia radiata, Forbes.
Wicklow, Ireland.

Fig. 580.

Oldhamia antiqua, Forbes.
Wicklow, Ireland.

fauna in England, and, with the exception of Eozoon, presently to be mentioned, in the world.

The slates of Llanberis and Penrhyn in Caernarvonshire, with their associated sandy strata, attain a great thickness, sometimes about 3,000 feet. They are perhaps not more ancient than the Harlech and Barmouth beds last mentioned, for they may represent the deposits of fine mud thrown down in the same sea, on the borders of which the sands above mentioned were accumulating. In some of these slaty rocks at Bray Head in Ireland, immediately opposite Anglesea and Caernarvon, two species of fossils have been found, to which the late Professor E. Forbes gave the name of *Oldhamia* (figs. 579, 580). The nature of these organisms is still a matter of discussion among naturalists. The beds of St. David's with *Lingulella*, pass down to a conglomerate, and a similar indication of a physical break is found in North Wales, according to Dr. Hicks and Professor Hughes. Below, are rocks the age of which is debated (p. 457).

North-west Scotland succession.—The North-western Highlands of Scotland contain, as has been already noticed, limestones of Arenig age (p. 440). The relation of these comparatively unfossiliferous strata to those above and below them, is still keenly debated. Murchison stated, in his last edition of Siluria, that he had little hesitation in suggesting that these limestones were of Lower Silurian age ; that they were covered conformably by quartz-rock, mica-schists, flagstones and a gneiss in ascending order. This gneiss Murchison termed the younger gneiss.

Beneath the limestone, are quartzites with Annelid tubes, of *Salterella Maccullochi*, resting on and overlapping red sandstone grit and conglomerate, to which a Cambrian age was given. The oldest rock or Fundamental Gneiss underlies these last unconformably.

According to this view, the Fundamental Gneiss of the West of Scotland and of the Isles is the oldest rock, and formed the base of the country ; upon it collected Cambrian and Lower Silurian rocks, and the whole of the Silurian strata above the Arenig were metamorphosed into Quartzite, Mica-schists, and Gneiss ; there being thus an older and a newer Gneiss.

These views are maintained by the Geological Survey of the United Kingdom, and are opposed by many distinguished geologists. Dr. Callaway's theory may be taken as fairly expressing the opinions of many geologists. He notices that the limestone is dolomitic in the main, there being very little true limestone; it overlies the grit and quartzite, and rests upon the

sandstone, &c. These three sets of strata are the Assynt series, and the sandstone is called Torridan. The upper or newer gneiss is the Caledonian, and the older or 'fundamental' is the Hebridean or Lewisian. Callaway considers—

1. That the Caledonian gneiss was laid down unconformably upon the Hebridean, so that instead of its being Silurian in age, it is older than Murchison's Cambrian.

2. Levelling of the country occurred, and the Caledonian was faulted down to the East along a S.S.W. line, and what was left on the up-cast side (Westwards) was denuded off. Hence the country or sea-floor at that time had two gneisses separated by a line of fault, and the Eastern gneiss, or Caledonian, was the latest.

3. The Assynt series was deposited on the Hebridean, and being derived from the wear and tear of land to the West, the deposits thinned out Eastwards, so that only the attenuated extension of its strata passed beyond the fault on to the Caledonian.

4. Upheaval of the Caledonian gneiss occurred along the old line of fault, and parallel faults were produced near it to the West. The overlying thin Assynt strata were fractured from their main mass.

5. Lateral thrust from the East forced the Caledonian gneiss up beyond the fault so as to double back the Assynt rocks and overlie them for some distance. At the same time, a parallel slice of Hebridean, lying to the West, was in like manner thrown over on to the quartzite and dolomite.

6. Denudation of the Assynt rocks, East of the great fault.

This theory indicates that the Silurian strata were not metamorphosed into mica-schist and gneiss, and that the gneisses are older than the Cambrian, the particular positions of the rocks being the product of faulting and lateral thrust.

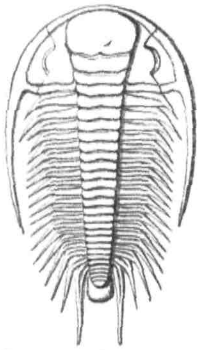
It is to be observed that Granites and Syenites intruded upon the Gneisses, and a Porphyry passes into the Assynt series.

Cambrian rocks of Bohemia (*Primordial Zone of Barrande*).—We have already seen, when treating of the Silurian strata of Bohemia, p. 444, that in the year 1846 Barrande gave the name of Étage C to the earliest fauna discovered by him in that country. This Étage C or primordial zone is now proved to be the equivalent of those subdivisions of the Cambrian groups which have been above described under the names of Menevian and Lingula Flags. M. Barrande found in Étage C, in Bohemia, Trilobites of the genera *Paradoxides*, *Conocoryphe*, *Ellipsocephalus*, *Sao*, *Arionellus*, *Hydrocephalus*, and *Agnostus*. M. Barrande pointed out that these primordial Trilobites have a peculiar facies of their own, dependent on the multiplication of their thoracic segments and the diminution of their caudal shield or pygidium.

One of the 'primordial' or Upper Cambrian Trilobites of the genus *Sao*, a form not found as yet elsewhere in the world, afforded M. Barrande a fine illustration of the metamorphosis of these creatures, for he traced them through no less than

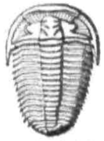
Fossils of the lowest Fossiliferous Beds in Bohemia, or 'Primordial Zone' of Barrande.

Fig. 581.



Paradoxides Bohemicus, Barr.
About ½ natural size.

Fig. 582.



Conocoryphe striata, Syn.
Conocephalus striatus, Emmrich.
½ natural size. Ginetz and Skrey.

Fig. 583.

Agnostus integer, Beyrich.
Nat. size and magnified.

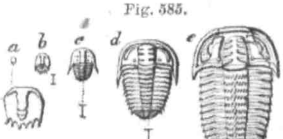
Fig. 584.

Agnostus Rex, Barr.
Nat. size, Skrey.

twenty stages of their development. A few of these changes have been selected for representation in the accompanying figures.

Besides the important Trilobita, there are two genera of Brachiopods, *Orthis* and *Orbicula*, a Pteropod of the genus *Theca*,

Fig. 585.



Sao hirsuta, Barrande, in its various stages of growth.

The small lines beneath indicate the true size. In the youngest state, *a*, no segments are visible; as the metamorphosis progresses, *b*, *c*, the body segments begin to be developed; in the stage *d* the eyes are introduced, but the facial sutures are not completed; at *e* the full-grown animal, half its true size, is shown.

and four Cystoidea. Beneath the Étage C, are very thick schists, conglomerates, quartzites, slates, and igneous rocks overlying gneiss.

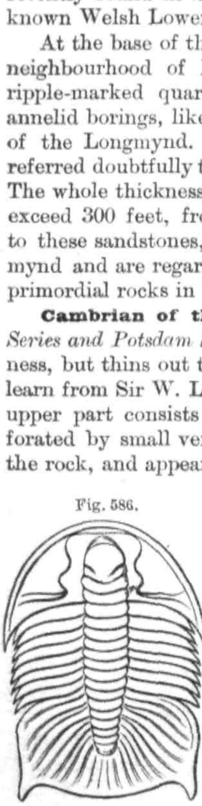
Cambrian of Sweden and Norway.—The Upper Cambrian beds in Sweden are the 'alum-schists.' These schists contain Trilobites belonging to the genera *Paradoxides*, *Olenus*, *Agnostus*, and others, some of which present rudimentary forms, like the

genus last mentioned, without eyes, and with the body segments scarcely developed, and others again have the number of segments excessively multiplied, as in *Paradoxides*. Dr. Torell has recently found in Sweden, the *Paradoxides Hicksii*, the well-known Welsh Lower Cambrian fossil.

At the base of the Cambrian strata in Sweden, which in the neighbourhood of Lake Wener are perfectly horizontal, lie ripple-marked quartzose sandstones with worm tracks and annelid borings, like some of those found in the Harlech grits of the Longmynd. Among these are some which have been referred doubtfully to plants. These are the 'fucoid sandstones.' The whole thickness of the Cambrian rocks of Sweden does not exceed 300 feet, from the equivalents of the Tremadoc beds to these sandstones, which seem to correspond with the Longmynd and are regarded by Torell as older than any fossiliferous primordial rocks in Bohemia.

Cambrian of the United States and Canada—*Acadian Series and Potsdam Sandstone.*—This formation is of vast thickness, but thins out to the West and South, so that it is, as we learn from Sir W. Logan, only 700 feet thick in Canada. The upper part consists of sandstone containing fucoids, and perforated by small vertical holes, which are very characteristic of the rock, and appear to have been made by annelids (*Scolithus linearis*). The lower portion is a conglomerate with quartz pebbles. I have seen the Potsdam sandstone on the banks of the St. Lawrence, and on the borders of Lake Champlain, where, as at Keesville, it is a white quartzose fine grained grit, almost passing into quartzite. It is divided into horizontal ripple-marked beds, very like those of the Lingula Flags of Britain, and is replete with a small round-shaped Trilobite of the genus *Olenellus*, which divide the rock into parallel planes, in the same manner as do the scales of mica in micaceous sandstones. Among the shells of this formation in Wisconsin are species of *Lingulella* and *Orthis*, and several trilobites of the genera *Conocephalus*, *Obolella*, and *Dikelocephalus* (fig. 586). On the banks of the St. Lawrence, near Beauharnois, many fossil footprints have been observed on the rippled layers. They are supposed by Sir Richard Owen to be the trails of more than one species of Crustacean, probably allied to the King Crab, or *Limulus*.

Fig. 586.



Dikelocephalus Minnesotensis, Dale Owen. ½ diameter. A large Trilobite of the Olenoid group. Potsdam Sandstone. Falls of St. Croix, on the Upper Mississippi.

Recent investigations, by the naturalists of the Canadian Geological Survey, have shown that slates and schists of Potsdam Sandstone age extend from New York to Newfoundland, and contain Trilobites similar in genera though not in species to those found in the European Cambrian strata.

Pre-Cambrian Rocks.—The Cambrian rocks are underlaid by great thicknesses of metamorphic and intrusive igneous rocks, amongst which the only traces of life are found in the Laurentian formation in Canada and possibly in Bavaria. In Europe it is usual to term all rocks beneath the Cambrian Archæan ; in America they are the Huronian and Laurentian formations.

The discrepancy of opinion regarding the geological construction of the North-west Highlands, mentioned on p. 453, will prepare the student for similar diversities of opinion regarding the age of the rocks which underlie the fossiliferous Lower Cambrian of Wales and its equivalent formations elsewhere. The Geological Survey consider that there is no break present, and that the volcanic and metamorphic rocks underlying the fossiliferous strata are really part of one great Cambrian series.

On the other hand, many geologists of equal ability consider that they have sufficient evidence to state that there is a great break at the base of the fossiliferous series, a conglomerate being there which contains the results of the denudation of two if not three more ancient groups of rocks. One of these lower groups was volcanic, and the other and older was metamorphic. They (with a third, according to Dr. Hicks) are included under the term Pre-Cambrian, but their relation to the typical North American Pre-Cambrian rocks is not known.

Dr. Hicks's researches in the St. David's area tend to prove that there is a vast thickness of unfossiliferous rocks beneath the Cambrian conglomerate in descending order.

1. *The Pebidian.*—A volcanic series, made up of ejectamenta, more or less stratified, alternating with schistose, metamorphosed clays, and sandstones. Spherulitic felstone, greenish and purplish felspathic breccias, silvery-white schists, purple shales, light-coloured green clay slates, greenish, reddish, and purplish indurated ashes, often conglomeratic, are found, and also contemporaneous lava in the form of felstone. The upper beds are red and purple ashy schists. The Pebidian series rests unconformably on the next group, and has a different structure to the overlying Cambrian, to the basal conglomerate of which it contributes. The rocks are mostly basic in character.

2. *The Arvonian* consists of breccias, hälleflintas, and quartz

felsites, of rhyolites, and the rocks are acidic. Dr. Hicks states that this series rests unconformably on the underlying Dimetian.

3. *The Dimetian.*—These lowest rocks, the base of which has not been seen, form an anticlinal axis, flanked by the Pebidian, and partly by unaltered Cambrian rocks. The rocks are quartz porphyries, often with double pyramids of quartz, sub-angular masses of quartz, and crystals of felspar in a matrix of grey or green felspathic material. Fine-grained quartz felsites, ashy shale-like rocks, with more or less satisfactory lines of lamination occur, and compact granitoid rocks, without mica, and quartz in excess over the orthoclase felspar. Granitoid gneiss, quartziferous breccias and schists, quartzites, purplish and greenish chloritic-looking bands and crystalline limestone are present. These rocks contribute to the conglomerate at the base of the Cambrian, and were metamorphosed before their denudation occurred.

Professor Bonney has shown that a quartz felsite, or ancient igneous flow, closely resembling more modern rhyolites, underlies the Cambrian conglomerate in North-west Caernarvonshire. And both he and Dr. Hicks have proved the occurrence of a Pre-Cambrian series greatly resembling that of South Wales, in Anglesea. The series has been noticed also in Shropshire and Charnwood.

The oldest rock in Scotland is that called by Sir R. Murchison 'the fundamental gneiss,' which is found in the North-west of Ross-shire, and in Sutherlandshire (p. 453), and forms the whole of the adjoining island of Lewis, in the Hebrides. It has a strike from north-west to south-east, nearly at right angles to the metamorphic strata of the Grampians. On this Fundamental, Hebridean or Lewisian gneiss, in parts of the Western Highlands, rocks of doubtful age, mentioned on page 453, rest unconformably. It seems highly probable that this ancient gneiss of Scotland may correspond in date with part of the great Laurentian group of North America.

The central axis of the Malvern chain consists of stratified but contorted schists, on which rest unconformably sandstones of Cambrian age. Many years since, Dr. Holl noted these rocks of Pre-Cambrian age in the ancient rocks of Malvern.

North American Pre-Cambrian rocks (*Huronian Series*).—The strata called the Huronian by Sir W. Logan are of vast thickness, and consist chiefly of a quartzite, with great masses of greenish chloritic slate, which sometimes include pebbles of crystalline rocks derived from the Laurentian formation, next to be described. Limestones are rare in this series, but one band of 300 feet in thickness has been traced for

considerable distances to the north of Lake Huron. Beds of greenstone are intercalated, conformably, with the quartzose and argillaceous members of this series. No organic remains have yet been found in any of the beds, which are about 18,000 feet thick, and rest unconformably on the Laurentian rocks.

Laurentian group.—Underlying the Huronian, northward of the river St. Lawrence, there is a vast series of crystalline rocks of gneiss, mica-schist, quartzite, and limestone, more than 30,000 feet in thickness, which have been called Laurentian, and which are already known to occupy an area of about 200,000 square miles. They had undergone great disturbing movements before the Potsdam sandstone and the other 'primordial' or Cambrian rocks were formed. The newer portion of the Laurentian series is unconformable to the older.

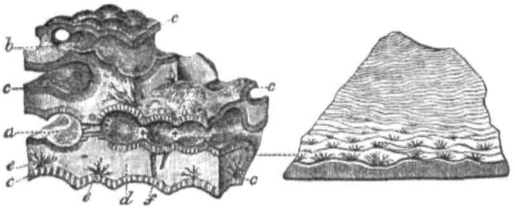
Upper Laurentian, Norian, or Labrador series.—The Upper Group, more than 10,000 feet thick, consists of metamorphic crystalline rocks in which no organic remains have yet been found. They consist of gneisses and granitoid rocks with Labradorite and anorthic felspars. There are also crystalline limestones and quartzites. These felspathic rocks sometimes form mountain masses almost without any admixture of other minerals; but at other times they include augite, which passes into hypersthene. The iridescent felspar Labradorite is found in Labrador. These rocks cover a great area in the Adirondac Mountains.

Lower Laurentian.—This formation, about 20,000 feet in thickness, is, as before stated, unconformable to that last mentioned; it consists in great part of massive gneiss of a reddish tint with orthoclase felspar. Beds of nearly pure quartz, from 400 to 600 feet thick, occur in some places. Hornblendic and micaceous schists are often interstratified, and beds of limestone usually crystalline. Beds of plumbago also occur, and it has naturally been conjectured that this pure carbon may have been of organic origin before it underwent metamorphism.

There are several of these limestones which have been traced to great distances, and one of them is from 700 to 1,500 feet thick. In the most massive of them Sir W. Logan observed in 1859 what he considered to be an organic body. It had been obtained the year before by Mr. J. McCulloch at the Grand Calumet on the river Ottawa. This fossil was examined in 1864 by Dr. Dawson of Montreal, who detected in it, by aid of the microscope, the distinct structure of a Rhizopod or Foraminifer. Dr. Carpenter and Professor T. Rupert Jones have since confirmed this opinion, comparing the structure to that of the well-known nummulite. It appears to have grown in lenticular or nodular masses, like *Stromatopora*, but not, as was once

imagined, in reefs. Parts of the original skeleton, consisting of carbonate of lime, are still preserved; while certain interspaces in the calcareous fossil have been filled up with serpentine and white augite. On this oldest of known organic remains Dr. Dawson has conferred the name of *Eozoon Canadense* (see figs. 587, 588); its antiquity is such that the distance of time which separated it from the Upper Cambrian period, or that of the Potsdam sandstone, may, says Sir W. Logan, be equal to the time which elapsed between the Potsdam sandstone and the Nummulitic limestones of the Tertiary period. Another organic-looking form somewhat resembling a cast of a chamber of a

Fig. 587. Fig. 588.



Eozoon Canadense, Daw. (after Carpenter). Oldest known organic body.

Fig. 587. *a*. Chambers of lower tier communicating at +, and separated from adjoining chambers at ⊙ by an intervening septum, traversed by passages. *b*. Chambers of an upper tier. *c*. Walls of the chambers, traversed by fine tubules. (These tubules pass with uniform parallelism from the inner to the outer surface, opening at regular distances from each other.) *d*. Intermediate skeleton, composed of homogeneous shell substance, traversed by stoloniferous passages (*f*), connecting the chambers of the two tiers. *e*. Canal system in intermediate skeleton, showing the arborescent sarcodic prolongations. (Fig. 588 shows these bodies in a decalcified state.) *f*. Stoloniferous passages.

Fig. 588. Decalcified portion of natural rock, showing *canal system* and the several layers. Natural size.

foraminifer, has been found, and, moreover, graphite is not uncommon.

The age of the gneissic rocks of the continent of Europe, of Hindostan, and of the Himalayas, is still a question very much debated, and one which will not be settled satisfactorily until very elaborate geological surveys have been aided by the labours of the petrologist; but nearly everywhere traces of a thick Pre-Cambrian metamorphic and volcanic series, with plutonic rocks, have been found, termed the Archæan. Intense regional metamorphism and volcanic outbursts characterise all these lower rocks, which are world-wide, but their identification with the Canadian series is not yet possible.

Supposed Azoic period.—The total absence of any trace of fossils has inclined many geologists to attribute the origin of the most ancient rocks to an Azoic period or one antecedent

to the existence of organic beings. Admitting, they say, the obliteration, in some cases, of fossils by plutonic action, we might still expect that traces of them would oftener be found in certain ancient systems of slate which can scarcely be said to have assumed a crystalline structure. But in urging this argument, it seems to have been forgotten that there are stratified formations of enormous thickness, and of various ages, some of them even of Tertiary date, which we know were formed after the earth had become the abode of living creatures, and are, nevertheless, in some districts, entirely destitute of all vestiges of organic bodies. In some, the traces of fossils may have been effaced by water and acids, at many successive periods; indeed, the removal of the calcareous matter of fossil shells is proved by the fact of such organic remains being often replaced by silica or other minerals, and sometimes by the space once occupied by the fossil being left empty or only marked by a faint impression.

It must be remembered that (excepting Eozoon) the earliest known fossils are Brachiopoda, Pteropoda, highly organised Crustacea, and Annelida. These can hardly have been the primitive forms of life, and their precursors doubtless have not descended to us as fossils, in consequence of the metamorphism of their containing rocks.

That there was an Azoic age before the globe was in a condition to support organic life hardly requires noticing, but there are no positive proofs of it afforded by observation.

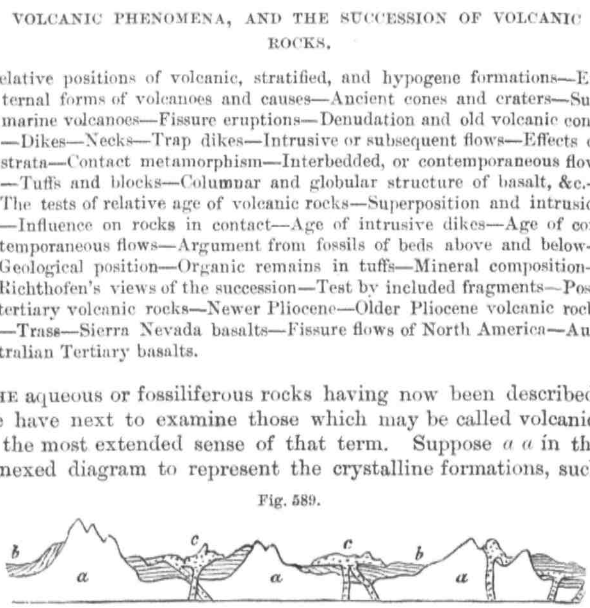
CHAPTER XXIX.

VOLCANIC PHENOMENA, AND THE SUCCESSION OF VOLCANIC ROCKS.

Relative positions of volcanic, stratified, and hypogene formations—External forms of volcanoes and causes—Ancient cones and craters—Submarine volcanoes—Fissure eruptions—Denudation and old volcanic cones—Dikes—Necks—Trap dikes—Intrusive or subsequent flows—Effects on strata—Contact metamorphism—Interbedded, or contemporaneous flows—Tuffs and blocks—Columnar and globular structure of basalt, &c.—The tests of relative age of volcanic rocks—Superposition and intrusion—Influence on rocks in contact—Age of intrusive dikes—Age of contemporaneous flows—Argument from fossils of beds above and below—Geological position—Organic remains in tuffs—Mineral composition—Richthofen's views of the succession—Test by included fragments—Post-tertiary volcanic rocks—Newer Pliocene—Older Pliocene volcanic rocks—Trass—Sierra Nevada basalts—Fissure flows of North America—Australian Tertiary basalts.

THE aqueous or fossiliferous rocks having now been described, we have next to examine those which may be called volcanic, in the most extended sense of that term. Suppose *a a* in the annexed diagram to represent the crystalline formations, such

Fig. 589.



a. Hypogene formations, stratified and unstratified.
b. Aqueous formations. *c*. Volcanic rocks.

as the granitic and metamorphic; *b b* the fossiliferous strata; and *c c* the volcanic rocks. These last are sometimes found, as was explained in the first chapter, breaking through *a* and *b*, sometimes overlying both, and occasionally alternating with the strata *b b*.

External form, structure, and origin of volcanic mountains.—The origin of volcanic cones with crater-shaped summits has been explained in the 'Principles of Geology' (chaps. xxiii. to xxvii.), where Vesuvius, Etna, Santorin, and Barren Island are described. The more ancient portions of those mountains or islands, formed long before the historic period, exhibit the same external features and internal structure as those of the extinct volcanoes of still higher antiquity. All these volcanoes

were produced by the same agencies which cause modern volcanic eruptions, and their materials belong to the same group of rocks and only slightly differ in degree and in chemical constitution.

Ancient and Modern Cones and Craters.—In regions where the eruption of volcanic matter took place in the open air, and where the surface has never since been subjected to great aqueous denudation, cones and craters may abound. Many hundreds of such cones still remain in Central France, in the ancient provinces of Auvergne, Velay, and Vivarais, where they form chains of hills. Although probably none of the eruptions have happened within the historical era, the ancient streams of lava may still be traced distinctly, descending from many of the craters, and following the lowest levels of the existing valleys.

The origin of the cone and crater of the modern volcano is now well understood, the growth of many having been watched during volcanic eruptions. A chasm or fissure first opens in the earth, from which great volumes of steam are evolved. The explosions are so violent as to splinter the rocks in which the volcanic vent is opened, and hurl up into the air fragments of broken stone, parts of which are shivered into minute portions. This stone is, in part, the rock which is penetrated by the uprushing steam, gases, and hot water, and mainly the volcanic rock which had been gradually forced up not quite to the surface. The showering down of the various ejected materials around the orifice of eruption, gives rise to a conical mound, in which the successive envelopes of ash and scoriæ form layers, dipping on all sides from a central axis. In the meantime a hollow, called a *crater*, has been kept open in the middle of the mound by the continued passage upwards of steam and other gaseous fluids. After a while, molten rock, quite liquefied, or *lava*, usually ascends through the vent by which the gases make their escape. Although extremely heavy, this lava is forced up by the expansive power of entangled gaseous fluids and steam. Quantities of the lava are also shot up into the air, and burst into minute fragments called ash. Blocks of solid lava are ejected also, being more or less scoriaceous. The lava sometimes flows over the edge of the crater, and thus thickens and strengthens the sides of the cone; but sometimes it breaks down the cone on one side (see fig. 590), and often it flows out from a fissure at the base of the hill, or at some distance from its base. The lava in cooling assumes a clinkery appearance, and is termed scoria. The amount of the slope of the cone depends upon the solidity or pasty condition of the component rocks.

Volcanoes are occasionally sub-marine, and build their way up to the surface, being exposed to the action of waves and tides. Some volcanic eruptions, especially those of the remote past, took place along lines of fracture of the earth's crust, and lava welled out, and sheets and flows were produced on a

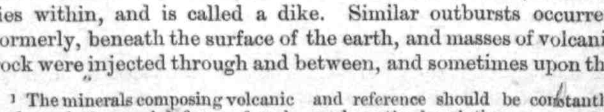
Fig. 590.

Part of the chain of extinct volcanoes called the Monts Dôme, Auvergne. (Scrope.)

grand scale without the formation of cones. Ancient volcanoes were as large as the modern, and as active, and followed the law of occurring on rising areas. Denudation has, in many instances, worn the old volcanoes nearly to the surface of the earth, yet some of the remains of the central vent and of the sloping layers around it enable the original dimensions to be estimated. All through the earth's history, internal heat, the presence of water in deeply seated rocks and of great pressure, have developed volcanicity. And the geographical distribution of volcanoes has been near great mountain chains, and not very remote from the sea.

At the present time, volcanic matter, in the form of lava[1] bursts forth under certain circumstances through the body of

Fig. 591.



Section across the Binn of Burntisland, Fife. (After Geikie.)
1. Sandstones; 2. Limestone; 3. Shales. *b b.* Interstratified basalts; *t t.* Bedded tuffs. T. Tuff of the great neck of the Binn. B. Basalt veins. (After Geikie.)

the volcanic cone, or if it does not come to the outside, it solidifies within, and is called a dike. Similar outbursts occurred formerly, beneath the surface of the earth, and masses of volcanic rock were injected through and between, and sometimes upon the

[1] The minerals composing volcanic rocks and the special forms of such rocks are described in the Appendix, and reference should be constantly made to the description.

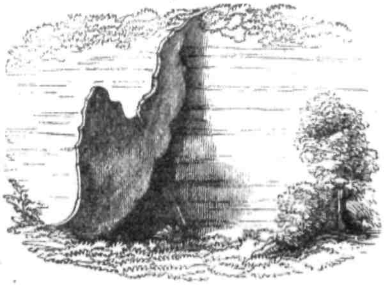
sedimentary strata. They are recognised as necks, dikes, intrusive or subsequent flows, and contemporaneous flows.

Necks.—The ancient vents of volcanoes preserved as 'necks,' and the remains of the ash and lava, or basalt, &c., are to be seen in many sections, and frequently have participated in the curving and folding of the surrounding rocks.

The necks, often of great size (fig. 591), consist of fragmentary volcanic rocks, agglomerates of fragments of basalt, felsite mixed with tuffs, and even of pieces of the strata burst through by the volcanic matters. The main mass may consist of solid basalt, diabase, quartz porphyry, and is often acidic in character where the surrounding lavas are basic.

Volcanic or Trap Dikes.—The leading varieties of the volcanic rocks, basalt, andesite, and trachyte, for example, are sometimes found in dikes penetrating stratified and unstratified formations, and these are examples of *intrusive* or *subsequent* volcanic ejections. Fissures have already been spoken of as occurring

Fig. 592.



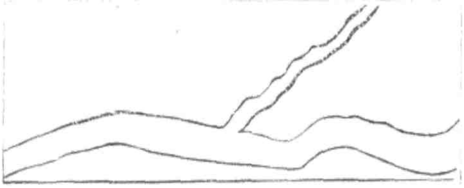
Dike in valley, near Brazen Head, Madeira. (From a drawing of Capt. Basil Hall, R.N.)

in all kinds of rocks, some a few feet, others many yards in width, and often filled up with earth or angular pieces of stone, or with sand and pebbles. Instead of such materials, suppose a quantity of melted stone to be driven or injected into an open rent, and there consolidated; we have then a tabular mass resembling a wall, and called a dike. It is not uncommon to find such dikes passing through strata of soft materials, such as tuff, scoriæ, or shale, which, being more perishable than the trap, are often washed away by the sea, rivers, or rain, in which case the dike stands prominently out on the face of precipices, or on the level surface of a country, as may be seen in Madeira (see fig. 592) and in many parts of Scotland.

In the islands of Arran and Syke, and in other parts of

Scotland, where sandstone, conglomerate, and other hard rocks are traversed by dikes of trap, the converse of the above phenomenon is also seen. The dike, having decomposed more rapidly than the containing rock, has once more left open the original fissure, often for a distance of many yards inland from the sea-coast. There is yet another case, by no means uncommon in Arran and other parts of Scotland, where the strata in contact with the dike, and for a certain distance from it, have been hardened, so as to resist the action of the weather more than the dike itself or the surrounding rocks. When this happens, two parallel walls of indurated strata are seen protruding above the general level of the country and following the course of the dike. In fig. 593, a ground plan is given of a ramifying dike

Fig. 593.



Ground plan of greenstone dikes traversing sandstone. Arran.

of greenstone, which I observed cutting through sandstone on the beach near Kildonan Castle, in Arran. The larger branch varies from 5 to 7 feet in width, which will afford a scale of measurement for the whole.

Every variety of volcanic rock may exist in dikes. Even tuffs and breccias may be found in them, for their materials may have been washed down into open fissures at the bottom of the sea, or showered into them from the air during eruption on the land. Some dikes of trap may be followed for leagues, uninterruptedly, in nearly a straight direction, as in the North of England, showing that the fissures which they fill must have been of extraordinary length. The trap may be amygdaloidal.

The materials of the dikes or flows which have been injected through and between strata were hot, pasty, and full of water and gases under pressure, and they acted upon and locally metamorphosed, more or less, the strata on either side and above and below them. The volcanic matter, moreover, became more or less crystalline on cooling. Usually, the sides and surfaces of such intrusive masses have a finer crystalline texture than

the middle part, and occasionally the surfaces in contact with the strata are glassy. Columnar structure, spheroidal structure, and jointing occur in the flow.

Rocks altered by volcanic dikes.—*Contact Metamorphism.*—After these remarks on the form and composition of dikes themselves, I shall describe the alterations which they sometimes produce in the rocks in contact with them. The changes are usually such as the heat of melted matter and of the entangled steam and gases might be expected to cause. In some instances, however, little or no change happened in the surrounding rocks.

Plas-Newydd: Dike cutting through shale.—A striking example of contact metamorphism, near Plas-Newydd, in Anglesea, has been described by Professor Henslow.[2] The dike is 134 feet wide, and consists of a rock which is a compound of triclinic felspar and augite. Strata of shale and argillaceous limestone, through which it cuts perpendicularly, are altered to a distance of 30, or even, in some places, of 35 feet from the edge of the dike. The shale, as it approaches the trap, becomes gradually more compact, and is most indurated where nearest the junction. Here it loses part of its schistose structure, but the separation into parallel layers is still discernible. In several places the shale is converted into hard porcellanous jasper. In the most hardened part of the mass, the fossil shells, principally *Producti*, are nearly obliterated; yet even here their impressions may frequently be traced. The argillaceous limestone undergoes analogous mutations, losing its early texture as it approaches the dike, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the dike.[3] Some garnets contain as much as 20 per cent. of lime, which they may have derived from the decomposition of the fossil shells or *Producti*. The same mineral has been observed, under very analogous circumstances, in High Teesdale, by Professor Sedgwick, where it also occurs in shale and limestone, altered by basalt.[4]

Antrim: Dike cutting through chalk.—In several parts of the county of Antrim, in the North of Ireland, Chalk with flints is traversed by basaltic dikes. The chalk is there converted into granular marble near the basalt, the change sometimes extending 8 or 10 feet from the wall of the dike, being greatest near

[2] Cambridge Transactions, vol. i. p. 402.

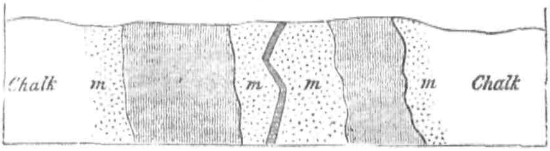
[3] Ibid. vol. i. p. 410.

[4] Cambridge Transactions, vol. ii. p. 175.

the point of contact, and thence gradually decreasing till it becomes evanescent. 'The extreme effect,' says Dr. Berger, 'presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive (metamorphic) limestone; the next state is saccharine, then fine grained and arenaceous; a compact variety, having a porcellanous aspect and a bluish-grey colour, succeeds: this, towards the outer edge, becomes yellowish white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour.'[5] All traces of organic remains are effaced in that part of the limestone which is most crystalline.

The annexed drawing (fig. 594) represents three basaltic dikes

Fig. 594.



Basaltic dikes in chalk in Island of Rathlin, Antrim.
Ground plan as seen on the beach. (Conybeare and Buckland.[6])

traversing the chalk, all within the distance of 90 feet. The chalk contiguous to the two outer dikes is converted into a finely granular marble, *m m*, as are the whole of the masses between the outer dikes and the central one. In some cases the change undergone by the chalk is of a chemical nature, and the rock, besides being indurated and crystallised, is also dolomitised. The entire contrast in the composition and colour of the intrusive and invaded rocks in these cases renders the phenomena peculiarly clear and interesting. Another of the dikes of the North-east of Ireland has converted a mass of red sandstone into hornstone. By another, the shale of the Coal-measures has been indurated, assuming the character of flinty slate; and at Portrush the shaly clay of the Lias has been changed into flinty slate, which still retains numerous impressions of *Ammonites*.[7]

It might have been anticipated that beds of coal would, from

[5] Dr. Berger, Trans. Geol. Soc. 1st ser. vol. iii. p. 172.

[6] Trans. Geol. Soc. 1st series, vol. iii. p. 210, and plate 10.

[7] Trans. Geol. Soc. 1st series, vol. iii. p. 213; and Playfair, Illust. of Huttonian Theory, s. 253.

their combustible nature, be affected in an extraordinary degree by the contact of melted rock. Accordingly, one of the greenstone dikes of Antrim, on passing through a bed of coal, reduces it to a cinder for the space of 9 feet on each side. At Cockfield Fell, in the North of England, a similar change is observed. Specimens taken at the distance of about 30 yards from the trap are not distinguishable from ordinary pit-coal; those nearer the dike are like cinders, and have all the character of coke; while those close to it are converted into a substance resembling soot.

It is by no means uncommon to meet with the same rocks, even in the same districts, almost wholly unchanged in the proximity of volcanic dikes. This great inequality in the effects of the igneous rocks may often arise from an original difference in their temperature, and in that of the entangled gases, such as is ascertained to prevail in different lavas, or in the same lava near its source and at a distance from it.

Interbedded or Contemporaneous Flows. — Volcanic flows, injected through strata, came to the surface, altered the underlying rocks there, and became scoriaceous on their upper part, and usually slightly at the lower surface also, during cooling. Deposits accumulated upon the flows, and were of course not altered physically or chemically by the previous process, for before they were deposited the volcanic flow had cooled. Such flows are called interbedded. They may have occurred during the progress of the deposition of strata all around, during any particular aspect of nature, and the fossils of the bed below and above the volcanic flow may be of the same species. Hence the flow thus interbedded, is said to be contemporaneous.

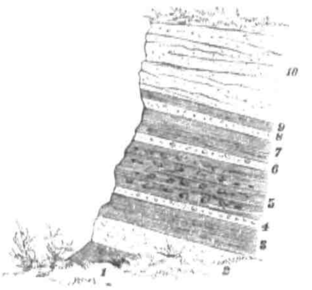
Interbedded or contemporaneous flows occur as compact sheets or as fragmental masses, and they conform to the plane of the underlying stratum. They are not found to have broken into or altered the overlying strata in any way. Both of their surfaces are scoriaceous or vesicular, and this peculiarity may extend through the whole sheet. Beds of tuff and other fallen materials may be interstratified with the flows.

The fragmentary volcanic rocks of the present day, such as ashes and blocks, fall on the country and do not influence the underlying strata. So in the geological periods the tuffs and ash-beds and the breccias covered strata in vast deposits, more or less stratified, and no metamorphism resulted.

In the illustration (fig. 595), from the Lower Carboniferous rocks of Linlithgowshire, a black shale (1) is at the bottom, and has the remains of terrestrial plants; and there are other

shales, numbered 3, 5, 7, 9. Between them are bands of pale yellowish volcanic tuff with lapilli or ejected pieces of ancient lava (Nos. 2, 4, 6, 8). A coarse agglomerate tuff is on the top of all (No. 10).

Fig. 595.



Interstratified volcanic tuff and shale. (After Geikie.)

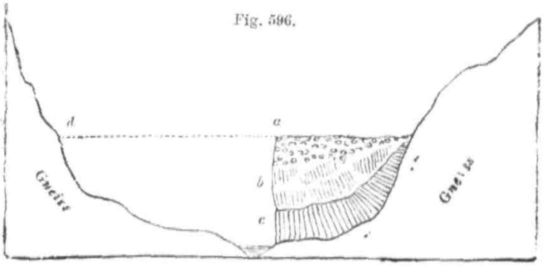
The distinction between volcanic materials which have collected on land and on the sea-floor, is not satisfactory. Tuffs or volcanic ashes collect on the floor of the Mediterranean, and are dredged up with the living mollusca, and historic lava flows have plunged into the Bay of Naples, and have become columnar in their structure. Probably the marine deposits of old were more fragmental than those which occurred on land.

Columnar and globular structure.—One of the characteristic forms assumed by volcanic rocks is the columnar, a structure often displayed in a very striking manner by basaltic lavas. The columns are sometimes straight, at others curiously curved and twisted; in section they are polygonal, and they are often divided longitudinally by equidistant joints, which sometimes exhibit curved surfaces of articulation; in certain cases the angles of one division of a column are found to project and to form processes which fit into sockets in the adjoining divisions. Columns of different varieties often occur in the same lava stream, the thick straight articulated columns being found in the lower, and the smaller curved forms in the upper portion; and the line of junction between the two kinds is in many cases very distinctly marked. It is this peculiar combination of columns of different kinds which gives rise to the beautiful and well-known features of the Isle of Staffa; it is equally well seen in many lavas of more recent date.

It being assumed that columnar trap has consolidated from a fluid state, the prisms are said to be always at right angles to the *cooling surfaces*. If these surfaces, therefore, instead of being either perpendicular or horizontal, are curved, the columns ought to be inclined at every angle to the horizon; and there is a beautiful exemplification of this phenomenon in one of the valleys of the Vivarais, a mountainous district in the South of France, where, in the midst of a region of gneiss, a geologist encounters unexpectedly several volcanic cones of loose sand

and scoriæ. From the crater of one of these cones, called La Coupe d'Ayzac, a stream of lava has descended and occupied the bottom of a narrow valley, except at those points where the river Volant, or the torrents which join it, have cut away portions of the solid lava. The accompanying sketch (fig. 596)

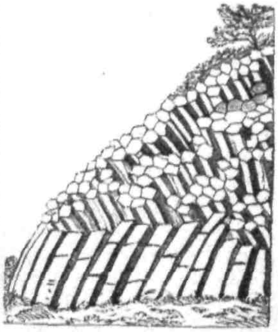
Fig. 596.



Lava of La Coupe d'Ayzac, near Antraigue, in the Department of Ardèche.

represents the remnant of the lava at one of these points. It is clear that the lava once filled the whole valley up to the dotted line *d a*; but the river has gradually swept away all below that line, while the tributary torrent has laid open a transverse section; by which we perceive, in the first place, that the lava is composed, as usual in this country, of three parts: the uppermost, at *a*, being scoriaceous; the second, *b*, presenting irregular prisms; and the third, *c*, with regular columns, which are vertical on the banks of the Volant, where they rest on a horizontal base of gneiss, but which are inclined at an angle of 45° at *g*, and are nearly horizontal at *f*, their position having been everywhere determined, according to the law before mentioned, by the form of the original valley.

Fig. 597.



Columnar basalt in the Vicentin. (Fortis.)

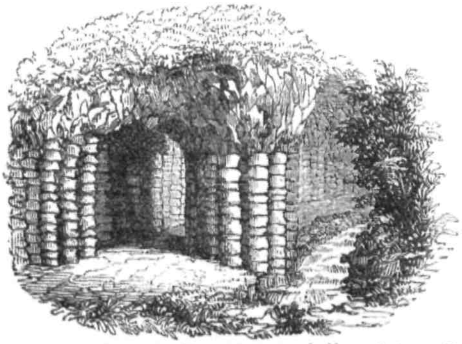
In the annexed fig. 597, a view is given of some of the inclined and curved columns which present themselves on the sides of the valleys in the hilly region north of Vicenza, in Italy, and at the foot of the higher Alps.[8] Unlike those of the Vivarais, last mentioned, the basalt of this

[8] Fortis, Mém. sur l'Hist. Nat. de l'Italie, tom. i. p. 233, plate 7.

country was evidently submarine, and the present valleys have since been hollowed out by denudation.

The columnar structure is by no means peculiar to the trap rocks of the basalt type; it is also observed in trachyte, and other acidic, felspathic rocks, although in these it is rarely exhibited in such regular polygonal forms, and never with the ball and socket joints, which form so conspicuous a feature in many basaltic columns. It has been already stated that basaltic columns are often divided by cross joints. Sometimes each segment, instead of an angular, assumes a spheroidal form, usually produced by weathering, so that a pillar is made up of a pile of balls, usually flattened, as in the Cheese-grotto at Bertrich-Baden, in the Eifel, near the Moselle (fig. 598). The

Fig. 598.



Basaltic pillars of the Käsegrotte, Bertrich-Baden, half way between Trèves and Coblentz. Height of grotto, from 7 to 8 feet.

basalt there is part of a small stream of lava, from 30 to 40 feet thick, which has proceeded from one of several volcanic craters, still extant, on the neighbouring heights.

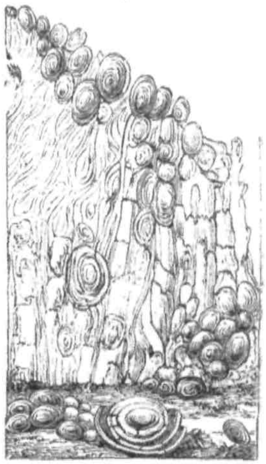
In some masses of decomposing basalt, greenstone, and other trap rocks, the globular structure is so conspicuous that the rock has the appearance of a heap of large cannon-balls. According to M. Delesse, the centre of each spheroid has been a centre of crystallisation, around which the different minerals of the rock arranged themselves symmetrically, during the process of cooling. But it was also, he says, a centre of contraction, produced by the same cooling, the globular form, therefore, of such spheroids being the combined result of crystallisation and contraction.[9] To this same contraction we may attribute some cases

[9] Delesse, Sur les Roches Globuleuses, Mém. de la Soc. Géol. de France, 2 sér. tom. iv.

of columnar structure in sedimentary strata, such as volcanic ash, shale and sandstone, which have been heated by the proximity of volcanic dikes.

Mr. Scrope gives as an illustration of this structure a resinous trachyte or pitchstone-porphyry in one of the Ponza islands, which rise from the Mediterranean, off the coast of Terracina and Gaeta. The globes vary from a few inches to three feet in diameter, and are of an ellipsoidal form (see fig. 599). The whole rock is in a state of decomposition, 'and when the balls,' says Mr. Scrope, 'have been exposed a short time to the weather, they scale off at a touch into numerous concentric coats, like those of a bulbous root, inclosing a compact nucleus. The laminæ of this nucleus have not been so much loosened by decomposition; but the application of a ruder blow will produce a still further exfoliation.' This spheroidal structure may be also seen in volcanic ash at Burntisland and elsewhere.

Fig. 599.



Globiform pitchstone. Chiaja di Luna, Isle of Ponza. (Scrope.)

Age of volcanic phenomena.—Having in the former part of this work referred the sedimentary strata to a long succession of geological periods, we have now to consider how far the volcanic formations can be classed in a similar chronological order. The tests of relative age in this class of rocks are four: 1st, superposition and intrusion, with or without alteration of the rocks in contact; 2nd, organic remains; 3rd, mineral characters; 4th, included fragments of older rocks.

Besides these four tests it may be said in a general way, that volcanic rocks of Primary or Palæozoic antiquity differ, in a certain degree, from those of the Secondary or Mesozoic age, and these again from the Tertiary and Recent. Not perhaps that they differed originally in a much greater degree than the modern volcanic rocks of one region, such as that of the Andes, differ from those of another, such as Italy, but because all rocks permeated by water, especially if its temperature be high, are liable to undergo a slow metamorphosis.

Although subaërial and submarine denudation remove, in

the course of ages, large portions of the cones and of the upper or more superficial products of volcanoes, yet these are sometimes preserved by the occurrence of subsidence, and subsequent covering up by sedimentary deposits. In this way the volcanic structures may be protected for ages; but even in this case they will not remain unaltered, because they will be percolated by water, often of high temperature, and charged with silica, iron, and other mineral ingredients, whereby gradual changes in the constitution of the rocks may be superinduced. Every geologist is aware how often silicified trees occur in volcanic tuffs, the perfect preservation of their internal structure showing that they had not decayed before the petrifying material was supplied.

The porous and vesicular nature of a large part, both of the basaltic and trachytic lavas, affords cavities in which silica, calcite, and zeolites are readily deposited. The minerals of the zeolite family, which are so commonly found in such amygdaloidal cavities, are closely related in composition to the felspars, but contain water. Daubrée and others have shown that the zeolites are formed by the action of percolating water upon the felspathic ingredients of rocks, while Bunsen has also shown in his researches into the volcanic rocks of Iceland that they may be formed directly in molten masses. From these considerations it follows that the perfect identity of appearance and character in very ancient and very modern volcanic formations is scarcely to be expected.

Age of intrusive dikes or flows.—After the differences between intrusive and contemporaneous volcanic flows have been considered, there should no difficulty in understanding the relation of the age of strata and of the flows which pass through or amongst or above them, especially when the strata are capable of being classified in definite geological groups or formations.

The dikes or flows must be younger than the strata they penetrated and influenced physically and chemically, for they occurred subsequently. How much younger does not always appear, because, for instance, a dike which was formed in a Tertiary age may come to the surface of the earth through Carboniferous strata which now form the sub-rock there, denudation having worn off all the overlying strata before or since the intrusion took place. Careful surveying, and the general distribution of the strata around the volcanic area, often enable the age to be settled. The mineral nature of the volcanic rock is often a guide, and altered basalts such as diabase indicate a greater age than ordinary basalt.

Age of interbedded or contemporaneous flows.—The

flow must be younger than the stratum it overlies, and has metamorphosed more or less, and is older than the stratum which rests on its scoriaceous upper surface. The fossils in the two sets of strata determine their age and the relative antiquity of the flow. Similar species being in the two sets of strata, the flow was truly contemporaneous, for it was an episode during a phase of nature.

Very different species of fossils being in the two sets of strata, lead to a less definite conclusion regarding the age of the flow, which may be of any age between that of the underlying and overlying.

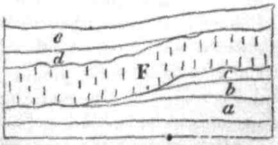
In the annexed figure (fig. 600) a flow, *b*, is placed under D, between the strata *a* and *c* of the Carboniferous formation. It appears to be interbedded and contemporaneous. But both the

Fig. 600.

strata *a* and *c* have been more or less altered by it, so that it was injected subsequently to the deposition of both of them. Under E, the same flow covers *a*, having pierced it and baked it on the top. Hence this flow is at the surface, and is younger than *a*.

We may, however, be easily deceived in supposing the volcanic rock to be intrusive, when in reality it is contemporaneous; for a sheet of lava, as it spreads over the bottom of the sea, cannot rest everywhere upon the same stratum, either because these have been denuded, or because, if newly thrown down, they thin out in certain places, thus allowing the lava to cross their edges. Besides, the heavy igneous fluid will often, as it moves along, cut a channel into beds of soft mud and sand. Suppose the submarine lava F (fig. 601) to have come in contact in this manner with the strata *a*, *b*, *c*, and that after its consolidation the strata *d*, *e*, are thrown down in a nearly horizontal position, yet so as to lie unconformably to F, the appearance of subsequent intrusion will here be complete, although the trap is in fact contemporaneous. We must not, therefore, hastily infer that the rock F is intrusive, unless we find the

Fig. 601.



overlying strata *d*, *e*, to have been altered at their junction, as if by heat.

The test of age by superposition is strictly applicable to all stratified volcanic tuffs, according to the rules already explained in the case of sedimentary deposits (see pp. 93–95).

Test of age by organic remains.—We have seen how, in the vicinity of active volcanoes, scoriæ, pumice, fine sand, and fragments of rock are thrown up into the air, and then showered down upon the land, or into neighbouring lakes or seas. In the tuffs so formed, shells, corals, or any other durable organic bodies which may happen to be strewed over the bottom of a lake or sea, will be embedded, and thus continue as permanent memorials of the geological period when the volcanic eruption occurred. Tufaceous strata thus formed in the neighbourhood of Vesuvius, Etna, Stromboli, and other volcanoes now in islands or near the sea, may give information of the relative age of these tuffs at some remote future period when the fires of these mountains are extinguished. By evidence of this kind we can establish a coincidence in age between volcanic rocks and the different Palæozoic, Secondary, and Tertiary fossiliferous strata.

The tuffs alluded to, may not always be marine, but may include, in some places, freshwater shells ; in others, the bones of terrestrial quadrupeds. The diversity of organic remains in formations of this nature is perfectly intelligible, if we reflect on the wide dispersion of ejected matter during late eruptions, such as that of the volcano of Coseguina, in the province of Nicaragua, January 19, 1835. Hot cinders and fine scoriæ were then cast up to a vast height, and covered the ground as they fell to the depth of more than 10 feet for a distance of 8 leagues from the crater in a southerly direction. Birds, cattle, and wild animals were scorched to death in great numbers, and buried in ashes. Some volcanic dust fell at Chiapa, upwards of 1,200 miles, not to leeward of the volcano as might have been anticipated, but to windward, a striking proof of a counter-current in the upper region of the atmosphere ; and some on Jamaica, about 700 miles distant to the north-east. In the sea, also, at the distance of 1,100 miles from the point of eruption, Captain Eden of the 'Conway' sailed 40 miles through floating pumice, among which were some pieces of considerable size. The importance of the fossils contained in the strata beneath and over contemporaneous flows has been noticed.

Test of age by mineral composition.—As sediment of homogeneous composition, when discharged from the mouth of a large river, is often deposited simultaneously over a wide

space, so a particular kind of lava flowing from a crater during one eruption, may spread over an extensive area; thus in Iceland, in 1783, the melted matter, pouring from Skaptar Jokul, flowed in streams in opposite directions, and caused a continuous mass the extreme points of which were 90 miles distant from each other. This enormous current of lava varied in thickness from 100 feet to 600 feet, and in breadth from that of a narrow river gorge to 15 miles. Now, if such a mass should afterwards be divided into separate fragments by denudation, we might still perhaps identify the detached portions by their similarity in mineral composition. Nevertheless, this test will not always avail the geologist; for, although there is usually a prevailing character in lava emitted during the same eruption, and even in the successive currents flowing from the same volcano, still, in many cases, the different parts even of one lava-stream, or, as before stated, of one continuous mass of trap, vary much in mineral composition and texture.

In Auvergne, the Eifel, and other countries where trachyte and basalt are both present, the trachytic rocks are for the most part older than the basaltic. These rocks do, indeed, sometimes alternate partially, as in the volcano of Mont Dore, in Auvergne; and in Madeira trachytic rocks overlie an older basaltic series; but the trachyte occupies more generally an inferior position, and is cut through and overflowed by basalt. It seems that in each region, where a long series of eruptions have occurred, the lavas containing felspar more rich in silica have been first emitted, and the escape of the more augitic kinds has followed.

Richthofen has given the subject of the succession of volcanic materials in North America and Europe great attention. He states that the volcanic rocks may be arranged in five groups, and that their appearance has been in the same order all over the world:—1, Propylite;[1] 2, Andesite; 3, Trachyte; 4, Rhyolite; 5, Basalt. Basalt, he affirms, is always the last of a series, although some of the other groups may not have been present. The explanation of the eruption of acidic volcanic materials in the first instance, and of basic rocks subsequently, may be that of Durocher, who believed that there was an outer layer of siliceous rocks, with 71 per cent. of silica, overlying one of basic rocks with about 51 per cent. The earlier explosions may have occurred in the outer layer.

The age of a volcanic dike or neck may be also inferred, and restricted within proper limits, by the fact of its participating or

[1] See Appendix.

not, in the curvings of strata, due to crust movements of known age.

Test by included fragments.—Where the evidence of superposition alone would be insufficient, we may sometimes discover the relative age of two trap rocks, or of an aqueous deposit and the trap on which it rests, by finding fragments of one included in the other. It is also not uncommon to find a conglomerate almost exclusively composed of rolled pebbles of trap, associated with some fossiliferous stratified formation in the neighbourhood of massive trap. If the pebbles agree, generally, in mineral character with the latter, we are then enabled to determine its relative age by knowing that of the fossiliferous strata associated with the conglomerate. The origin of such conglomerates is explained by observing the shingle beaches composed of trap pebbles in modern volcanoes, as at the base of Etna.

Post-Tertiary volcanic rocks.—I shall now select examples of contemporaneous volcanic rocks of successive geological periods, to show that igneous causes have been in activity in all past ages of the world. They have been perpetually shifting the places where they have broken out at the earth's surface, and we can sometimes prove that those areas which are now the great theatres of volcanic action were in a state of perfect tranquillity at remote geological epochs, and that, on the other hand, in places where at former periods the most violent eruptions took place at the surface and continued for a great length of time, there has been an entire suspension of igneous action in historical times. The most recent volcanic rocks in the British Islands are those occurring in the Hebrides and the North of Ireland, and the lowest rest upon Eocene plant-beds. They are products of three distinct periods of eruption, which with a strong show of probability may be correlated with the Eocene, Miocene, and Pliocene respectively,[2] but the denudation has been such that no perfect cones or craters have been preserved.

One portion of the lavas, tuffs, and trap-dikes of Etna, Vesuvius, and the island of Ischia has been produced within the historical era; another and a far more considerable part originated at times immediately antecedent, when the waters of the Mediterranean were already inhabited by the existing species of testacea, but when certain species of Elephant, Rhinoceros, and other quadrupeds now extinct, inhabited Europe.

Vesuvius.—I have traced in the 'Principles of Geology' the

[2] Judd, Secondary Rocks of Scotland, II. Ancient Volcanoes of the Hebrides. Quart. Journ. Geol. Soc. vol. xxx. p. 220. 1874.

history of the changes which the volcanic region of Campania is known to have undergone during the last 2,000 years. The aggregate effect of igneous operations during that period is far from insignificant, comprising as it does the formation of the modern cone of Vesuvius since the year 79, and the production of several minor cones in Ischia, together with that of Monte Nuovo in the year 1538. Lava-currents have also flowed upon the land and along the bottom of the sea—volcanic sand, pumice, and scoriæ have been showered down so abundantly that whole cities were buried—tracts of the sea have been filled up or converted into shoals—and tufaceous sediment has been transported by rivers and land-floods to the sea. There are also proofs, during the same recent period, of a permanent alteration of the relative levels of the land and sea in several places, and of the same tract having, near Puzzuoli, been alternately upheaved and depressed to the amount of more than 20 feet. In connection with these convulsions, there are found, on the shores of the Bay of Baiæ, recent tufaceous strata, filled with articles fabricated by the hands of man, and mingled with marine shells.

It has also been stated, that when we examine this same region, it is found to consist largely of tufaceous strata, of a date anterior to human history or tradition, which are of such thickness as to constitute hills from 500 to more than 2,000 feet in height. Some of these strata contain marine shells which are exclusively of living species, others contain a slight mixture, 1 or 2 per cent., of species not known as living.

The ancient part of Vesuvius is called Somma, and consists of the remains of an older cone which was partly destroyed by the first historic explosion.

Auvergne.—Although the latest eruptions in Central France seem to have long preceded the historical era, they are so modern as to have a very intimate connection with the present superficial outline of the country and with the existing valleys and river-courses. Among a great number of cones with perfect craters, one called the Puy de Tartaret sent forth a lava current which can be traced up to its crater and which flowed for a distance of 13 miles along the bottom of the present valley to the village of Nechers, covering the alluvium of the old valley in which were preserved the bones of an extinct species of horse, and of a lagomys and other quadrupeds all closely allied to recent animals, while the associated land-shells were of species now living, such as *Cyclostoma elegans*, *Helix hortensis*, *H. nemoralis*, *H. lapicida*, and *Clausilia rugosa*. That the current which has issued from the Puy de Tartaret may, nevertheless, be very ancient in reference to the events of human history, we may

conclude, not only from the divergence of the mammalian fauna from that of our day, but from the fact that a Roman bridge of such form and construction as continued in use only down to the fifth century, but which may be older, is now seen at a place about a mile and a-half from St. Nectaire. This ancient bridge spans the river Couze with two arches, each about 14 feet wide. These arches spring from the lava of Tartaret, on both banks, showing that a ravine precisely like that now existing had already been excavated by the river through that lava thirteen or fourteen centuries ago.

Puy de Côme.—The Puy de Côme and its lava-current, near Clermont, may be mentioned as another minor volcano of about the same age. This conical hill rises from the granitic platform, at an angle of between 30° and 40°, to the height of more than 900 feet. Its summit presents two distinct craters, one of them with a vertical depth of 250 feet. A stream of lava takes its rise at the western base of the hill instead of issuing from either crater, and descends the granitic slope towards the present site of the town of Pont Gibaud. Thence it pours in a broad sheet down a steep declivity into the valley of the Sioule, filling the ancient river-channel for the distance of more than a mile. The Sioule, thus dispossessed of its bed, has worked out a fresh one between the lava and the granite of its western bank; and the excavation has disclosed, in one spot, a wall of columnar basalt about 50 feet high.[3]

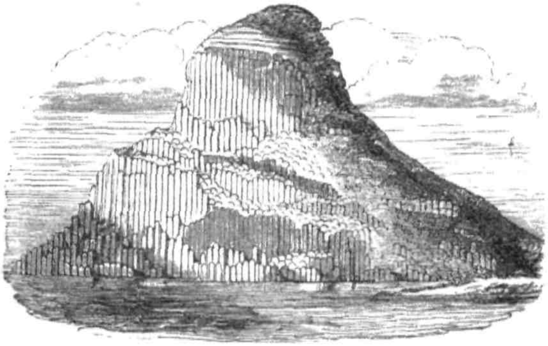
Newer Pliocene volcanic rocks.—The more ancient portion of Vesuvius and Etna originated at the close of the Newer Pliocene period, when less than ten, sometimes only one, in a hundred of the shells differed from those now living. In the case of Etna, it was before stated (p. 170) that Pleistocene formations occur in the neighbourhood of Catania, while the oldest lavas of the great volcano are Pliocene. These last are seen associated with sedimentary deposits at Trezza and other places on the southern and eastern flanks of the great cone.

Cyclopean Islands.—The Cyclopean Islands, called by the Sicilians Dei Faraglioni, in the sea-cliffs of which these beds of clay, lava, and tuff are laid open to view, are situated in the Bay of Trezza, and may be regarded as the extremity of a promontory severed from the mainland. Here numerous proofs are seen of submarine eruptions, by which the argillaceous and sandy strata were invaded and cut through, and tufaceous breccias formed. Enclosed in these breccias are many angular and hardened fragments of laminated clay in different states of alteration by heat, and intermixed with volcanic sands.

[3] Scrope's Central France, p. 60, and plate.

The loftiest of the Cyclopean islets, or rather rocks, is about 200 feet in height, the summit being formed of a mass of stratified clay, the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata dip to the N.W., and rest on a mass of columnar lava (see fig. 602) in which the tops of the pillars are weathered, and so rounded as to be often

Fig. 602.



View of the Isle of Cyclops in the Bay of Trezza.
(Drawn by Capt. Basil Hall, R.N.)

hemispherical. In some places in the adjoining and largest islet of the group, which lies to the north-eastward of that represented in the drawing (fig. 603), the overlying clay has been greatly altered and hardened by the igneous rock, and occasionally contorted in the most extraordinary manner; yet the lamination has not been obliterated, but, on the contrary, rendered much more conspicuous, by the indurating process.

In the woodcut (fig. 604), I have represented a portion of the altered rock, a few feet square, where the alternating thin laminæ of sand and clay are contorted in a manner often observed in ancient metamorphic schists. A great fissure, running from east to west, nearly divides this larger island into two parts, and lays open its internal structure. In the section thus exhibited, a dike of lava is seen, first cutting through an older mass of lava, and then penetrating the superincumbent tertiary strata. In one place the lava ramifies and terminates in thin veins, from a few feet to a few inches in thickness. The arenaceous laminæ are much hardened at the point of contact, and the clays are converted into siliceous schist. In this island the altered rocks assume a honeycomb structure on their weathered surface, singularly contrasted with

the smooth and even outline which the same beds present in their usual soft and yielding state.

Dikes of Palagonia.—Dikes of vesicular and amygdaloidal lava are also seen traversing marine tuff or peperino, west of

Fig. 603.

Contortions of strata in the largest of the Cyclopean Islands.

Fig. 604.

Newer pliocene strata invaded by lava, Isle of Cyclops (horizontal section).

a. Lava. *b.* Laminated clay and sand. *c.* The same altered.

Palagonia, some of the pores of the lava being empty, while others are filled with carbonate of lime. In such cases we may suppose the tuff to have resulted from showers of volcanic

Fig. 605.

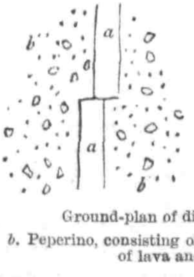
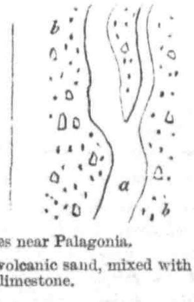


Fig. 606.



Ground-plan of dikes near Palagonia.

a. Lava. *b.* Peperino, consisting of volcanic sand, mixed with fragments of lava and limestone.

sand and *scoriæ*, together with fragments of limestone, thrown out by a submarine explosion similar to that which gave rise to Graham Island in 1831. When the mass was, to a certain

degree, consolidated, it may have been rent open, so that the lava ascended through fissures, the walls of which were perfectly even and parallel. In one case, after the melted matter that filled the rent (fig. 605) had cooled down, it must have been fractured and shifted horizontally by a lateral movement.

In the second figure (fig. 606), the lava has more the appearance of a vein, which forced its way through the peperino. It is highly probable that similar appearances would be seen, if we could examine the floor of the sea in that part of the Mediterranean where the waves have recently washed away the new volcanic island; for when a superincumbent mass of ejected fragments has been removed by denudation, we may expect to see sections of dikes traversing tuff, or, in other words, sections of the channels of communication by which the subterranean lavas reached the surface.

Madeira.—Although the more ancient portion of the volcanic eruptions by which the island of Madeira and the neighbouring one of Porto Santo were built up, occurred, as we shall presently see, in the Miocene period, a still larger part of the island is of Pliocene date. That the latest outbreaks belonged to the Newer Pliocene period, I infer from the close affinity to the present flora of Madeira of the fossil plants preserved in a leaf-bed in the north-eastern part of the island. These fossils, associated with some lignite in the ravine of the river San Jorge, can none of them be proved to be of extinct species, but their antiquity may be inferred from the following considerations. Firstly—The leaf-bed, discovered by Mr. Hartung and myself in 1853, at the height of 1,000 feet above the level of the sea, crops out at the base of a cliff formed by the erosion of a gorge, cut through alternating layers of basalt and scoriæ, the product of a vast succession of eruptions of unknown date, piled up to a thickness of 1,000 feet, and which were all poured out after the plants, of which about 20 species have been recognised, flourished in Madeira. These lavas are inclined at an angle of about 15° to the north, and came down from the great central region of eruption. Their accumulation implies a long period of intermittent volcanic action, subsequently to which the ravine of San Jorge was hollowed out. Secondly—Some few of the plants, though perhaps all of living genera, are supposed to be of species not now existing in the island. They have been described by Sir Charles Bunbury and Professor Heer, and the former first pointed out that many of the leaves are of the laurel type and analogous to those now flourishing in the modern forests of Madeira. He also recognised among them the leaves of *Woodwardia radicans*, and *Davallia Canariensis*,

ferns now abundant in Madeira. Thirdly—Fossil land shells, 5 per cent. of which are extinct, are found in the blown sands upon the leaf-bed.

Older Pliocene Period.—*Italy.*—In Tuscany, as at Radicofani, Viterbo, and Aquapendente, and in the Campagna di Roma, submarine volcanic tuffs are interstratified with the Older Pliocene strata of the Subapennine hills in such a manner as to leave no doubt that they were the products of eruptions which occurred when the shelly marls and sands of the Subapennine hills were in the course of deposition. These rocks are well known to rest conformably on the Subapennine marls, even as far south as Monte Mario in the suburbs of Rome. On the exact age of the deposits of Monte Mario new light has recently been thrown by a careful study of their marine fossil shells. After the comparison of no less than 160 species of shells with the shells of the Coralline Crag of Suffolk, so well described by Mr. Searles Wood, the specific agreement between the British and Italian fossils is found to be so great, if we make due allowance for geographical distance and the difference of latitude, that we can have little hesitation in referring both to the same period, or to the Older Pliocene of this work. It is highly probable that, between the oldest trachytes of Tuscany and the newest rocks in the neighbourhood of Naples, a series of volcanic products might be detected of every age from the Older Pliocene to the historical epoch.

Pliocene Volcanoes of the Eifel.—Some of the most perfect cones and craters in Europe may be seen on the left or west bank of the Rhine, near Bonn and Andernach. They exhibit characters distinct from any which I have observed elsewhere, owing to the large part which the escape of aqueous vapour has played in the eruptions and the small quantities of lava emitted. The fundamental rocks of the district are grey and red sandstones and shales, with some associated limestones, replete with fossils of the Devonian or Old Red Sandstone group. The volcanoes broke out in the midst of these inclined strata, and when the present systems of hills and valleys had already been formed. The eruptions occurred sometimes at the bottom of deep valleys, sometimes on the summit of hills, and frequently on intervening platforms. In travelling through this district we often come upon them most unexpectedly, and may find ourselves on the very edge of a crater before we had been led to suspect that we were approaching the site of any igneous outburst. Thus, for example, on arriving at the village of Gemund, immediately south of Daun, we leave the stream, which flows at the bottom of a deep valley, in which

strata of sandstone and shale crop out. We then climb a steep hill, on the surface of which we see the edges of the same strata dipping inwards towards the mountain. When we have ascended to a considerable height, we see fragments of scoriæ sparingly scattered over the surface; until, at length, on reaching the summit, we find ourselves suddenly on the edge of a *tarn*, or deep circular lake-basin called the Gemunder Maar. In it we recognise the ordinary form of a crater, for which we have been prepared by the occurrence of scoriæ scattered over the surface of the soil. But on examining the walls of the crater we find precipices of sandstone and shale which exhibit no signs of the action of heat; and we look in vain for those beds of lava and scoriæ, dipping outwards on every side, which we have been accustomed to consider as characteristic of volcanic vents. As we proceed, however, to the opposite side of the lake, we find a considerable quantity of scoriæ and some lava, and see the whole surface of the soil sparkling with volcanic sand, and strewed with ejected fragments of half-fused shale, which preserves its laminated texture in the interior, while it has a vitrified or scoriaceous coating.

Other crater-lakes of circular or oval form, and hollowed out of similar ancient strata, occur in the Upper Eifel, where copious aëriform discharges have taken place, throwing out vast heaps of pulverised shale into the air. I know of no other extinct volcanoes where gaseous explosions of such magnitude have been attended by the emission of so small a quantity of lava.

It appears that when some of these volcanoes were in action, the river valleys had already been eroded to their present depth.

Trass.—The tufaceous alluvium called *trass*, which has covered large areas in the Eifel, and choked up some old river valleys now partially re-excavated, is unstratified. Its base consists almost entirely of pumice, in which are included fragments of basalt, and other lavas, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees. If, as is probable, this trass was formed during the period of volcanic eruptions, it may have originated in the manner of the moya of the Andes.

We may easily conceive that a similar mass might now be produced, if a copious evolution of gases should occur in one of the lake-basins. If a breach should be made in the side of the cone, the flood would sweep away great heaps of ejected fragments of shale and sandstone, which would be borne down into the adjoining valleys. Forests might be torn up by such a flood, and thus the occurrence of the numerous trunks of trees

dispersed irregularly through the trass can be explained. The manner in which this trass conforms to the shape of the present valleys implies its comparatively modern origin, probably one dating no further back than the Pliocene period.

United States.—In the Western Territories of the United States, the Sierra Nevada has a great thickness of auriferous gravels of Pliocene age covered by basalt, and this is a part of the result of a grand series of fissure eruptions, and also of flows from volcanoes, which continued probably into the Historic period. Such flows are vast in amount in other regions, and were one of the great phases in the development of the physical features of the Continent after the upheaval of the mountain systems. The great lakes to the west of the Rocky Mountains were in existence when the outflow took place in and to the west of the mountains. The basalts form important features in Nevada, Oregon, Idaho, Utah, &c.

Australia.—Vast volcanic flows occurred in Australia during the Tertiary ages, and those of Queensland and of Victoria are of great importance, both geologically and economically. Marine and freshwater deposits, the ages of which can be determined by the contained fossils, are covered or rest upon great thicknesses of dolerites. There are two series of outflows, an upper and a lower, and the auriferous deposits are covered by the upper and rest on the lower. Where the upper or pliocene basalt is absent or has been denuded, the sedimentary strata at once give the gold-seeker his guide; for if they contain marine fossils, they are older than the age when the denudation of exposed auriferous quartz reefs permitted the accumulation of auriferous deposits. The marine strata are of Miocene age, and the basalt covering them underlies the auriferous freshwater deposits, the results of the denudation of higher ground than that covered by the older and marine series. In the northern part of Queensland, north of lat. 21°, the upper volcanic series consists of well-defined craters and great lava flows, which are older than the Pleistocene marsupials (p. 128), the foreshadowers of the existing fauna. In Queensland, these Pliocene flows cap a 'desert sandstone,' and in Victoria, gravels, conglomerates, cement-beds, and other Pliocene auriferous deposits. The Victorian Pliocene volcanic flow is at a considerable altitude, and has been much denuded.

CHAPTER XXX.

AGE OF VOLCANIC ROCKS—*continued.*

Volcanic rocks of the Miocene Period—Madeira—Grand Canary—Azores—Australia—Oligocene Volcanic rocks—The Eifel—Tertiary Volcanic rocks of Auvergne—Eocene Volcanic rocks of Monte Bolca, the Hebrides and Ireland—Hindostan—Trap of Cretaceous period—Oolitic Period—Triassic Period—Permian Period—Carboniferous Period—Erect trees buried in Volcanic ash in the Island of Arran—Old Red Sandstone Period—Silurian Period—Cambrian Period—Laurentian Volcanic rocks.

Volcanic rocks of the Miocene Period.—*Madeira.*—The greater part of the volcanic eruptions of Madeira, as we have already seen (p. 483), belong to the Pliocene period, but the most ancient of them are of Miocene date, as is shown by the fossil shells included in the marine tuffs which have been upraised at San Vicente, in the northern part of the island, to the height of 1,300 feet above the level of the sea. A similar marine and volcanic formation constitutes the fundamental portion of the neighbouring island of Porto Santo, forty miles distant from Madeira, and is there elevated to an equal height, and covered, as in Madeira, with lavas of subaërial origin.

The largest number of fossils have been collected from the tuffs and conglomerates and some beds of limestone in the island of Baixo, off the southern extremity of Porto Santo. The species amount, in this single locality, to more than sixty, of which about fifty are mollusca, but many are only casts. Some of the shells probably lived on the spot during the intervals between eruptions, and some may have been cast up into the water or air together with muddy ejections, and, falling down again, have been deposited on the bottom of the sea. The hollows in some of the fragments of vesicular lava, of which the breccias and conglomerates are composed, are partially filled with calc-sinter, being thus half converted into amygdaloids. Among the fossil shells common to Madeira and Porto Santo, large Cones, Strombs, and Cowries are conspicuous among the univalves, and *Cardium*, *Spondylus*, and *Lithodomus* among the lamellibranchiate bivalves, and among the Echinoderms the large *Clypeaster altus*, an extinct European Miocene form.

The largest list of fossils has been published by Mr. Karl Mayer, in Hartung's 'Madeira.' Mr. Mayer identifies one-third of the Madeira shells with known European Miocene forms.

Grand Canary.—In the Canaries, especially in the Grand

Canary, the same marine Upper Miocene formation is found. Stratified tuffs, with intercalated conglomerates and lavas, are there seen in nearly horizontal layers in sea-cliffs about 300 feet high near Las Palmas. Mr. Hartung and I were unable to find marine shells in these tuffs at a greater elevation than 400 feet above the sea; but as the deposit to which they belong reaches to the height of 1,100 feet or more in the interior, we conceive that an upheaval of at least that amount has taken place. The *Clypeaster altus*, *Spondylus gæderopus*, *Pectunculus pilosus*, *Cardita calyculata*, and several other shells, serve to identify this formation with that of the Madeiras, and *Ancillaria glandiformis*, which is not rare, and some other fossils, remind us of the faluns of Touraine.

These tuffs of the southern shores of the Grand Canary, containing the Miocene shells, appear to be about the same age as the most ancient volcanic rocks of the island. Over the marine lavas and tuffs trachytic and basaltic products of subaërial volcanic origin, between 4,000 and 5,000 feet in thickness, have been piled, the central parts of the Grand Canary reaching the height of about 6,000 feet above the level of the sea. A large portion of this mass is of Pliocene date, and some of the latest lavas have been poured out since the time when the valleys were already excavated to within a few feet of their present depth.

Azores.—In the island of St. Mary's, one of the Azores, marine fossil shells have long been known. They are found on the north-east coast on a small projecting promontory called Ponta do Papagaio (or Point Parrot), chiefly in a limestone about 20 feet thick, which rests upon, and is again covered by, basaltic lavas, scoriæ, and conglomerates. The pebbles in the conglomerate are cemented together with carbonate of lime.

One of the most characteristic and abundant of the species, *Cardium Hartungi*, not known as fossil in Europe, is very common in Porto Santo and Baixo, and serves to connect the Miocene fauna of the Azores and the Madeiras. In some of the Azores, as well as in the Canary Islands, the volcanic fires are not yet extinct, as the recorded eruptions of Lanzerote, Teneriffe, Palma, St. Michael's, and others attest. The late soundings (1873) of H.M.S. 'Challenger' have shown the Azores, Canaries, Cape de Verde Islands, &c., to be merely the highest summits of a great submerged mountain ridge, comparable with the Andes of South America both in extent and altitude, as well as in the volcanic character of many of its most elevated peaks.

Australia.—The newer volcanic deposits of Australia have been slightly noticed (p. 486), and it is now requisite to state

that the lower and Miocene series appears to have come up through fissures, and to have covered a vast extent of country, overflowing all the older formations. This outburst is called the Lower Volcanic in Queensland, and also in Victoria, where, with the Pliocene flows, it covers about 40,000 square miles.

Oligocene.—*The Eifel.*—A large portion of the volcanic rocks of the Lower Rhine and the Eifel are coeval with the Oligocene deposits to which most of the 'Brown-Coal' of Germany belongs. The Tertiary strata of that age are seen on both sides of the Rhine, in the neighbourhood of Bonn, resting unconformably on highly inclined and vertical strata of Silurian and Devonian rocks. The Brown-Coal formation of that region consists of beds of loose sand, sandstone, and conglomerate, clay with nodules of clay ironstone, and occasionally silex. Layers of light brown, and sometimes black lignite are interstratified with the clays and sands, and often irregularly diffused through them. They contain numerous impressions of leaves and stems of trees, and are extensively worked for fuel, whence the name of the formation. In several places, layers of trachytic tuff are interstratified, and in these tuffs are leaves of plants identical with those found in the Brown-Coal, showing that, during the period of the accumulation of the latter, some volcanic products were ejected. The igneous rocks of the Westerwald, and of the mountains called the Siebengebirge, consist partly of basaltic and partly of trachytic lavas, the latter being in general the more ancient of the two. There are many varieties of trachyte, some of which are highly crystalline, resembling a coarse-grained granite, with large separate crystals of felspar. Trachytic tuff is also very abundant.

Miocene and Oligocene volcanic rocks of Auvergne.—The extinct volcanoes of Auvergne and Cantal in Central France seem to have commenced their eruptions in the Oligocene period, but to have been most active during the Miocene and Pliocene eras.

The earliest monuments of the Tertiary period in that region are lacustrine deposits of great thickness, in the lowest conglomerates of which are rounded pebbles of quartz, mica-schist, granite, and other non-volcanic rocks, without the slightest intermixture of igneous products. To these conglomerates succeed argillaceous and calcareous marls and limestones, containing Oligocene shells and bones of mammalia, the higher beds of which sometimes alternate with volcanic tuff of contemporaneous origin. After the filling up or drainage of the ancient lakes, huge piles of trachytic and basaltic rocks, with volcanic breccias, accumulated to a thickness of several thousand feet, and were

superimposed upon granite, or the contiguous lacustrine strata. The greater portion of these igneous rocks appears to have originated during the Miocene and Pliocene periods; and extinct quadrupeds of those eras, belonging to the genera *Mastodon*, *Rhinoceros*, and others, were buried in ashes and beds of alluvial sand and gravel, which owe their preservation to overspreading sheets of lava.

In Auvergne, the most ancient and conspicuous of the volcanic masses is Mont Dore, which rests immediately on the granitic rocks standing apart from the freshwater strata. This great mountain rises suddenly to the height of several thousand feet above the surrounding platform, and retains the shape of a flattened and somewhat irregular cone, the slope of which is gradually lost in the high plain around. This cone is composed of layers of scoriæ, pumice-stones, and their fine detritus, with interposed beds of trachyte and basalt, which descend often in uninterrupted sheets until they reach and spread themselves round the base of the mountain.[1] Conglomerates, also, composed of angular and rounded fragments of igneous rocks, are observed to alternate with the above; and the various masses are seen to dip off from the central axis, and to lie parallel to the sloping flanks of the mountain. The summit of Mont Dore terminates in seven or eight rocky peaks, where no regular crater can now be traced, but where we may easily imagine one to have existed, which may have been shattered by earthquakes, and have suffered degradation by aqueous agents. Originally, perhaps, like the highest crater of Etna, it may have formed an insignificant feature in the great pile, and, like it, may frequently have been destroyed and renovated.

Respecting the age of the great mass of Mont Dore, we cannot come at present to any positive decision, because no organic remains have yet been found in the tuffs, except impressions of the leaves of trees of species not yet determined. It has already been stated (p. 200) that the earliest eruptions must have been posterior in origin to those grits and conglomerates of the freshwater formation of the Limagne which contain no pebbles of volcanic rocks. But there is evidence at a few points, that some eruptions took place before the great lakes were drained, while others occurred after the desiccation of those lakes, and when deep valleys had already been excavated through freshwater strata.

The valley in which the cone of Tartaret, above mentioned

[1] Scrope's Central France, p. 98.

(p. 480), is situated affords an impressive monument of the very different dates at which the igneous eruptions of Auvergne have happened; for while the cone itself is of Pleistocene date, the valley is bounded by lofty precipices composed of sheets of ancient columnar trachyte and basalt, which once flowed from the summit of Mont Dore in some part of the Miocene period. These Miocene lavas had accumulated to a thickness of nearly 1,000 feet before the ravine was cut down to the level of the river Couze, a river which was at length dammed up by the modern cone and the upper part of its course transformed into a lake.

Eocene volcanic rocks.—*Monte Bolca.*—The fissile limestone of Monte Bolca, near Verona, has for many centuries been celebrated in Italy for the number of perfect Ichthyolites which it contains. When I visited Monte Bolca, in company with Sir Roderick Murchison, in 1828, we ascertained that the fish-bearing beds were of Eocene date, containing well-known species of Nummulites, and that a long series of submarine volcanic eruptions, evidently contemporaneous, had produced beds of tuff, which are cut through by dikes of basalt. There is evidence here of a long series of submarine volcanic eruptions of Eocene date, and during some of them, as Sir R. Murchison has suggested, shoals of fish were probably destroyed by the evolution of heat, noxious gases, and tufaceous mud, just as happened when Graham's Island was thrown up between Sicily and Africa in 1831, at which time the waters of the Mediterranean were seen to be charged with red mud, and covered with dead fish over a wide area.[2]

Tertiary volcanoes of Ireland and the Hebrides.—In all probability a volcanic area stretched from the North of Ireland, inclusive, northwards, to the remotest Hebrides, and far into the Atlantic, reaching to Greenland in the far north, during the early Tertiary ages.

Enormous flows of basalt, vast intrusive dikes, beds of scoriaceous material, ash, and lapilli, found in the North of Ireland and the Hebrides, and the columnar basalt of the Giant's Causeway and of the Isle of Staffa, attest the former volcanic activity which occurred on those areas. The basalts frequently rest on old soils and secondary rocks. The surface of the chalk in the North of Ireland, covered and altered by the basalt, the beds of soil baked into bright red porcellanite, and the masses of vegetable matter in Ireland and the Hebrides converted into charcoal or remaining as lignite, prove that the old lavas flowed

[2] Principles of Geology, chap. xxvii. 11th ed.

over land. Volcanic mud-streams and old river-gravels have been overwhelmed in the districts, and ancient lacustrine bog-iron-making areas have been covered up and preserved. The resemblance of these old volcanic outflows to the modern is very remarkable, and from the number of them and intercalated ash-beds, it is evident that the volcanic activity was continued during a long period. Professor Judd has shown from the results of his careful researches that the remains of great volcanic cones are to be found in the Hebrides, and that smaller Puys were even formed at the conclusion of the great volcanic age. The latest fossiliferous rocks covered by these sheets of lava are Plant-beds, and late research tends to the belief that the flows are not all of one age. In the North of Ireland, on the Antrim coast, the old lava-flows consist of trachytes, porphyries, and pitch-stones, covered by amygdaloidal basalts, and with volcanic ash and beds of bole. The upper part consists of massive sheets of columnar basalt, which usually ceases to be noticed quite at the top. The plant remains are in a mineral called Bauxite, in clay iron ore, and many are silicified. The plant-zone is above the trachytic flow, and beneath the upper columnar basalt.

An examination of the plant remains and siliceous trunks of trees leads to the belief that they are of later age than the Bagshot series ; but no satisfactory geological horizon can be given to them. The plant remains of the Isle of Mull, with *Onoclea sensibilis*, *Thuja*, *Platanus*, *Corylus*, and *Sequoia*, are similar to one of the Greenland floras, and are older than the Antrim beds, being most probably of Eocene age. Hence the great volcanic series was possibly poured forth during the Eocene, and certainly during the Oligocene and Miocene periods.

The intrusive masses vary in dimensions, from veins or strings to vast bosses, constituting mountain groups like the Cuchullin Hills of Skye. Agreeing with the old lavas in composition, they vary in their mineralogical composition and texture. Some are basalts, others are glassy tachylites, others are highly crystalline gabbros. Moreover, felstone veins occur, related on the one hand to pitchstone and obsidian, and to masses of felsite, syenite-granite, and granite. As a rule, the largest intrusive masses are composed of the most highly crystalline or granitic rocks. Agglomerates and breccias of ejected blocks occur.

The Isle of Mull.—Professor Judd[5] gives an admirable description of this extinct volcanic area. The island, with the adjacent peninsula of Morvern and various small islands, forms part of a great plateau of sheets of basalt nearly 2,000 feet

[5] Quart. Jour. Geol. Soc. v. xxx. p. 242.

thick, and which has suffered from denudation, being traversed by numerous sounds and fjords. It is brought into abrupt contact with the palæozoic rocks by a fault, which has a throw of about 1,600 feet. A group of mountains, about twelve miles in diameter, rises in the midst of the plateau, the greatest altitude of Beinn More being 3,172 feet. The smooth pyramidal masses of some of these hills, and the wild irregular-shaped peaks of others, contrast with the tabular and terraced aspect of the trap or basalt area. This is occasioned by the latter having been formed by successive lava flows, whilst the peaks in the interior of the island were the result of intrusive masses mixed with volcanic agglomerates and breccias, all greatly denuded.

The basis of the central group of mountains consists of highly siliceous intrusive rocks. Granite, hornblendic, or with the usual mica, constitutes the centre, and merges outwards insensibly into felsite. Lying on the skirts of these, are thick masses of felstones, disposed in regular sheets, presenting amygdaloidal structure, and which alternate with beds of scoriæ, lapilli, and ashes, containing included blocks of the stratified rocks of the island. Professor Judd remarks that whilst these beds undoubtedly represent the lavas and fragmentary materials ejected from a volcanic vent, the central hills of granite felsite are no less eruptive masses, and they give off numerous veins into the overlying lavas and surrounding strata.

But rising through these masses of granite is a great mass of gabbro, or basic rocks, from which proceed innumerable veins, sheets, and intrusive masses of irregular form, that traverse the whole of the siliceous rocks in every direction. These gabbros graduate into dolerites.

The geological history of the island points to a period when an old land surface, in the early Tertiary period, suffered from volcanic eruption of fragmentary matters, blocks, ashes, and scoriæ, accompanied by the outpouring of acidic lavas now forming felstones. The accumulating mass was forced upwards by the rising liquid rock from which the streams of lava were fed, and injections into the neighbouring rocks occurred. Slow consolidation, under vast pressure, produced the masses and veins of granite and felsite. The period of the outpouring and injection of the acidic mineral masses was followed by inactivity. Then a second series of eruptions took place, the relics of the first having undergone great decay. Explosions had destroyed the old acidic rocks; subsidences had taken place in portions of the mass, and denudation had removed the agglomerates and ashes in many places, exposing the granites and felsites of the central portion.

The second eruption was of basic rocks, which were forced through the older ones, producing veins in them, dykes in and through them, and small cones. The basaltic lava flowed far and wide, covering up the country beyond the old flows, and accumulated gradually, to a vast thickness.

The last phase of the volcanic activity was the formation of 'Puys,' or small cones, on the flows, the materials of which burst through the underlying granitic and basaltic plateau, the ejectamenta being acidic and basic. Very considerable local metamorphism of the Palæozoic and Secondary strata occurred.

Denudation has progressed on an enormous scale since the last period of activity, which preceded the Glacial epoch, and *the result has been to wear down nearly the whole of the flanks* of the great volcano, which must have had a circumference of 40 miles, and an altitude of more than fourteen thousand feet. Professor Judd remarks that he was led to infer that changes took place in the position of the axis of eruption during the volcanic period of Mull, as was illustrated in the case of Etna, in the Principles of Geology.[4]

The eruptions were subsequent to the accumulation of the plant-bed at Ardtun, which has an Eocene age attributed to it; and there were long intervals between the series of volcanic phenomena.

Hindostan.—A vast volcanic area exists in the Western and Central parts of the Peninsula of Hindostan, called the Deccan and Malwa Trap. It covers 200,000 square miles, and is found as numerous flows of earthy basalt, amounting to 3,000 feet in thickness. This vast deposit seems to have come from fissure eruptions, as no volcanic cones have been preserved, and the flows covered an old terrestrial surface of the Upper Cretaceous age.

The flows took a vast time, for lake-beds exist amongst them in succession, with their fossils silicified; and denudation has progressed, enormous amounts of superficial change having occurred also. The Trap is older than the Nummulitic age.

Cretaceous Period.—M. Virlet has shown in his account of the geology of the Morea, that certain traps in Greece are of Cretaceous date; as those, for example, which alternate conformably with cretaceous limestone and greensand between Kastri and Damala in the Morea. They consist in great part of diallage rocks and serpentine, and of an amygdaloid with calcareous kernels, and a base of serpentine. In certain parts of the Morea, the age of these volcanic rocks is established by the following proofs: first, the lithographic limestones of the Cre-

[4] Ed. xi. vol. ii. pp. 9–14.

taceous era are cut through by trap, and then a conglomerate occurs, at Nauplia and other places, containing in its calcareous cement many well-known fossils of the chalk and greensand, together with pebbles formed of rolled pieces of the same serpentinous trap, which appear in the dikes above alluded to.[5]

Period of Oolite and Lias.—Although the green and serpentinous trap rocks of the Morea belong chiefly to the Cretaceous era, as before mentioned, yet it seems that some eruptions of similar rocks began during the Oolitic period; and it is probable that a large part of the trappean masses, called ophiolites in the Apennines, and associated with the limestone of that chain, are of corresponding age. Important trap rocks in the Rajmahal district of Hindostan are of Jurassic age.

Trap of the New Red Sandstone Period.—In the southern part of Devonshire, trappean rocks are associated with New Red Sandstone, and, according to Sir H. De la Beche, have not been intruded subsequently into the sandstone, but were produced by contemporaneous volcanic action. Some beds of grit, mingled with ordinary red marl, resemble sands ejected from a crater; and in the stratified conglomerates occurring near Tiverton, are many angular fragments of trap porphyry, some of them one or two tons in weight, intermingled with pebbles of other rocks. These angular fragments were probably thrown out from volcanic vents, and fell upon sedimentary matter then in the course of deposition.[6]

Trap of the Permian Period.—The investigations of Professor Archibald Geikie in Ayrshire and at Nithsdale in Dumfriesshire have shown that some of the volcanic rocks in that county are of Permian age. In Germany, the older part of the Permian rocks contain abundant contemporaneous volcanic rock. Eruptive rocks of this age also occur at Botzen in the Tyrol.

Trap of the Carboniferous Period.—Two extensive developments of trap rocks occur in the Carboniferous basin of the Forth in Scotland. One of these is well exhibited along the shores of Fifeshire, where the igneous masses consist of basalt, sometimes with olivine, and of dolerites. These appear to have been erupted while the sedimentary strata were in a horizontal position, and to have suffered the same dislocations which those strata have subsequently undergone. In the associated volcanic tuffs of this age are found, not only fragments of limestone, shale, flinty slate, and sandstone, but also pieces of coal. Other traps connected with the Carboniferous formation may be traced along the south margin of Stratheden, and constitute a

[5] Boblaye and Virlet, Morea, p. 23.
[6] De la Beche, Proc. Geol. Soc. vol. ii. p. 198.

ridge parallel with the Ochils, extending from Stirling to near St. Andrews. These consist almost exclusively of dolerite, becoming, in a few instances, earthy and amygdaloidal. They are either interbedded with, or intruded among, the sandstone, shale, limestone, and ironstone of the Lower Carboniferous. I examined these trap rocks in 1838, in the cliffs south of St. Andrews, where they consist in great part of stratified tuffs, which are curved, vertical and contorted, like the associated coal-measures. In the tuff I found fragments of carboniferous shale and limestone, and intersecting veins of dolerite.

The Cement-stone group (p. 357) accumulated, writes Geikie,[7] in a region of shallow lagoons, islets, and coal growths, which was dotted over with innumerable active volcanic vents. The eruptions continued into the time of the Carboniferous limestone, but ceased before the deposition of the Millstone grit. Close-grained basalts, or coarsely grained, granitoid in texture, were formed with felsites, porphyries and tuffs.

Beneath this group there are evidences of vast volcanic flows, some sheets being 1,500 feet thick. The most persistent zone of volcanic rocks in the Scottish Carboniferous system is that which succeeds the lower part of the Calciferous Sandstones. Composed of successive sheets of porphyrites and tuffs, it sweeps in long isolated ranges of hills from Arran and Bute on the west to the mouth of the estuary of the Forth on the east, and from the Campsie Fells on the north to the heights of Ayrshire, and still further south in Berwickshire, Liddesdale, and the English border.

Fife—Flisk Dike.—A trap dike was pointed out to me by Dr. Fleming, in the parish of Flisk, in the northern part of the county of Fife, which cuts through the grey sandstone and shale, forming the lowest part of the Old Red Sandstone, but which may probably be of carboniferous date. It may be traced for many miles, passing through the amygdaloidal and other traps of the hill called Norman's Law in that parish. In its course it affords a good exemplification of the passage from the ordinary trappean into a highly crystalline texture. Professor Gustav Rose, to whom I submitted specimens of this dike, found it to be dolerite, and composed of greenish black augite and Labrador felspar, the latter being the most abundant ingredient. A small quantity of magnetic iron, perhaps titaniferous, is also present.

Erect trees buried in volcanic ash at Arran.—An interesting discovery was made in 1867 by Mr. E. A. Wünsch in the lower

[7] Geikie, Text-Book of Geology, p. 739.

carboniferous strata of the north-eastern part of the island of Arran. In the sea-cliff, about five miles north of Corrie, near the village of Laggan, strata of volcanic ash occur, forming a solid rock cemented by carbonate of lime and enveloping trunks of trees, determined by Mr. Binney to belong to the genera *Sigillaria* and *Lepidodendron*. I visited the spot in company with Mr. Wünsch in 1870, and saw that the trees with their roots, of which about fourteen had been observed, occur at two distinct levels in volcanic tuffs, parallel to each other, and inclined at an angle of about 40°, having between them beds of shale and coaly matter seven feet thick. It is evident that the trees were overwhelmed by a shower of ashes from some neighbouring volcanic vent, as Pompeii was buried by matter ejected from Vesuvius. The trunks, several of them from three to five feet in circumference, remained with their Stigmarian roots spreading through the stratum below, which had served as a soil. The trees must have continued for years in an upright position after they were killed by the shower of volcanic ash, giving time for a partial decay of the interior, so as to afford hollow cylinders into which the spores of plants were wafted. These spores germinated and grew, until finally their stems were petrified by carbonate of lime like some of the remaining portions of the wood of the containing *Sigillaria*.

Arthur's Seat, Edinburgh, is the relic of a volcanic focus, and commenced as a fissure in the Calciferous Sandstone age, which gave forth trachytic and basaltic lavas, of which much was forced amongst the surrounding strata. Probably the eruption took place in shallow water, and after a while elevation occurred and agglomerates collected, forming the higher part of the mass. Extinction was followed by a certain amount of subsidence. The volcanic relics have participated in the general movements of the area since the Carboniferous age, and have suffered denudation. Professor Geikie considers that a second series of eruptions took place in the Tertiary age.

Great sheets of melaphyre, felstone, and tuff are found in the Carboniferous limestone of Limerick, and to the north in Ireland. In Derbyshire, sheets of contemporaneous lava called 'toadstone' occur in the limestone, and flows have been found of the same age in the Isle of Man.

Trap of the Old Red Sandstone Period.—By referring to the section explanatory of the structure of Forfarshire, already given (p. 51), the reader will perceive that beds of conglomerate, No. 3, occur in the middle of the Old Red Sandstone system, 1, 2, 3, 4. The pebbles in these conglomerates are sometimes composed of gneiss and quartzose rocks, sometimes

exclusively of different varieties of trap, which last, although purposely omitted in the section referred to, is often found either intruding itself in amorphous masses and dikes into the old fossiliferous tilestones, No. 4, or alternating with them in conformable beds. All the different divisions of the red sandstone, 1, 2, 3, 4, are occasionally intersected by dikes, but they are very rare in Nos. 1 and 2, the upper members of the group consisting of red shale and red sandstone. These phenomena, which occur at the foot of the Grampians, are repeated in the Sidlaw Hills; and it appears that in this part of Scotland volcanic eruptions were most frequent in the earlier part of the Old Red Sandstone period. These lavas are for the most part of the felspathic class, their structure being sometimes porphyritic, at others amygdaloidal; in the latter case the kernels of the latter being sometimes calcareous, often calcedonic, and forming beautiful agates. In a more or less decomposed condition these felspathic lavas are known under the name of claystones. With them occur beds of stratified tuff and conglomerate, also compact felspar, and tuff. Some of these rocks look as if they had flowed as lavas over the bottom of the sea, and enveloped quartz pebbles which were lying there, so as to form conglomerates with a base of greenstone, as is seen in Lumley Den, in the Sidlaw Hills. On either side of the axis of this chain of hills (see section, p. 51), the beds of massive trap, and the tuffs composed of volcanic sand and ashes, dip regularly to the south-east or north-west, conformably with the shales and sandstones.

But the geological structure of the Pentland Hills, near Edinburgh, shows that igneous rocks were there formed during the Devonian or 'Old Red' period. These hills are 1,900 feet high above the sea, and consist of conglomerates and sandstones of Devonian age, resting on the inclined edges of grits and slates of Upper Silurian date. The contemporaneous volcanic rocks intercalated in this lower Old Red Sandstone, consist of felspathic lavas or felstones, with agglomerates and ashy beds.

In the Harz, in Nassau, Saxony, &c., evidences of contemporaneous volcanic action have been observed in Devonian rocks, in the form of diabase, tuff, and porphyroid, and the tuff bands are often crowded with organic remains.

Silurian volcanic rocks.—The Upper Silurian series of the West of Ireland show successive sheets of basalt (Eurite) and tuffs forming conspicuous bands amongst the stratified rocks. The volcanic series of the Lake District of the North-West of England is of vast thickness, and intervened between the Skiddaw slates and the Coniston limestone and shale. It

occupied much of the Bala age, and all that of the Llandeilo, and part of the Arenig epoch of Wales.

The Snowdonian hills, in Caernarvonshire, consist, in great part, of volcanic tuffs, the oldest of which are interstratified with the Bala and Llandeilo beds. There are contemporaneous felsitic lavas of this era, which altered the slates on which they repose, having doubtless been poured out over them, in a melted state, whereas the slates which overlie them, having been deposited after the lava had cooled and consolidated, have entirely escaped alteration. But there are greenstones associated with the same formation, which, although they are often conformable to the slates, are in reality intrusive rocks. They alter the stratified deposits both above and below them.

Volcanic action occurred largely during the formation of the Arenig strata, and felsitic and rhyolitic lavas were erupted, and interstratified with fossiliferous deposits. Tuffs added to the bulk of the whole. Cader Idris, the Arans, Arenig Mountains, and others are thus built up.

Cambrian volcanic rocks.—On the western flank of the Malverns in Herefordshire, some black shales belonging to the Upper Lingula Flags are interstratified with thin sheets of vesicular lava that were probably erupted beneath the sea contemporaneously with the deposition of the muddy sediment. The shales lying beneath the volcanic rock are white, as if calcined by the molten lava, while those lying above have retained their normal black colour. In speaking of this ancient volcanic outburst, the late Professor Phillips said: 'One might mistake the ferruginous and cellular stone for the subaërial reliquiæ of a volcano in Auvergne,' a district where the erupted volcanic matter is clearly contemporaneous with the associated sedimentary deposits.

Pre-Cambrian volcanic rocks.—Beneath the lowest fossiliferous Cambrian rocks, and the basal conglomerate of the formation in Wales and elsewhere, is a vast volcanic series, the agglomerates, tuffs, and flows of which have been altered to a certain extent by metamorphic action. These Pebidian rocks have already been noticed (p. 457). Beneath the Hälleflinta group below, is the great Dimetian series, in which metamorphic and volcanic acidic rocks were intruded upon by granitoid rocks.

Laurentian volcanic rocks.—The Laurentian rocks in Canada, especially in Ottawa and Argenteuil, are the oldest intrusive masses yet known. They form a set of dikes of a fine-grained dolerite, composed of felspar and pyroxene, with occasional scales of mica and grains of pyrites. Their width varies from a few feet to a hundred yards, and they have a columnar

structure, the columns being truly at right angles to the plane with the dike. Some of the dikes send off branches. These dolerites are cut through by intrusive syenite, and this syenite, in its turn, is again cut and penetrated by porphyritic felsite. All these trap rocks appear to be of Laurentian date, as the Cambrian and Huronian rocks rest unconformably upon them. Whether some of the various conformable crystalline rocks of the Laurentian series, such as the coarse-grained granitoid and porphyritic varieties of gneiss, exhibiting scarcely any signs of stratification, and some of the serpentines, may not also be of volcanic origin, is a point very difficult to determine in a region which has undergone so much metamorphic action.

CHAPTER XXXI.

PLUTONIC ROCKS.

Plutonic rocks formed at great depths—Kinds—Granite group—Scenery of Granitic countries—Denudation of Granite—Tors—Rude columnar structure—Exposure of Granite by great denudation of other rocks—Granite veins—Different ages of Plutonic rocks—Test by relative position—Intrusion and alteration—Mineral composition—Included fragments—Tertiary—Cretaceous—Jurassic—Carboniferous — Silurian — Laurentian and Archæan granites.

THE plutonic rocks may be treated of, next in order, as they are most nearly allied to the volcanic class already considered. I have described, in the first chapter, these plutonic rocks as the unstratified division of the crystalline or hypogene formations, and have stated that they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, whether thrown up into the air or the sea. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lavas.

From these and other peculiarities, it has been inferred that the granites have been formed at considerable depths in the earth, and have cooled and crystallised slowly, under great pressure, where the contained gases could not expand. The volcanic rocks, on the contrary, although they also have risen up from below, have cooled from a melted state more rapidly upon or near the surface. From this hypothesis of the great depth

at which the granites originated, has been derived the name of 'Plutonic rocks.'

The heat which in every active volcano extends downwards to indefinite depths, must produce, simultaneously, very different effects near the surface and far below it; and we cannot suppose that rocks resulting from the crystallising of fused matter under a pressure of several thousand feet, much less several miles, of the earth's crust, can exactly resemble those formed at or near the surface. Hence the production at great depths of a class of rocks analogous to the volcanic, and yet differing in many particulars, might have been predicted, even had we no plutonic formations to account for.

It has, however, been objected, that if the granitic and volcanic rocks were simply different parts of one great series, we ought to find volcanic dikes passing upwards into lava and downwards into granite, in mountain chains. But we may answer that our vertical sections are usually of small extent; and if we find in certain places a transition from trap to porous lava, and in others a passage from granite to trap, it is as much as could be expected of this evidence.

The plutonic formations also agree with the volcanic in having veins or ramifications proceeding from central masses into the adjoining rocks, and causing alterations in these last, which will be presently described. They also resemble trap in containing no organic remains; but they differ in being more uniform in texture, whole mountain masses of indefinite extent appearing to have originated under conditions precisely similar.

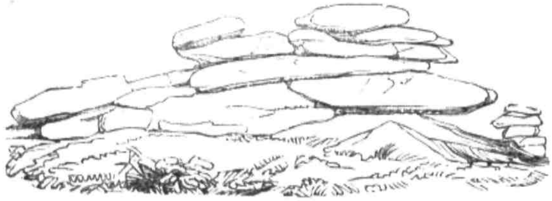
The two principal members of the Plutonic family of rocks are Granite and Syenite, and it is necessary to number with them Diorite, Tonalite, and Gabbro.[1]

Granite.—Granite often preserves a very uniform character throughout a wide range of territory, frequently forming hills of a peculiar rounded form, clad with a scanty vegetation. It occurs frequently in vast masses in the midst of mountain ranges, and the metamorphic rocks, such as gneiss and mica schist, are in contact with its flanks. It may project as an important feature in the scenery, forming continuous and grand mountains, or only be noticed as lines of bosses which are evidently continuous with intrusive veins from a main mass. Professor Judd has explained the nature of the granite hills of Mull, which are the cores of ancient volcanoes. Vast surfaces of the earth are covered by granite which does not rise into high mountains, but maintains a rolling bossy outline.

[1] See Appendix.

The surface of the rock is for the most part in a crumbling state, and with bosses here and there; and the hills are often surmounted by piles of stones, or Tors, like the remains of a

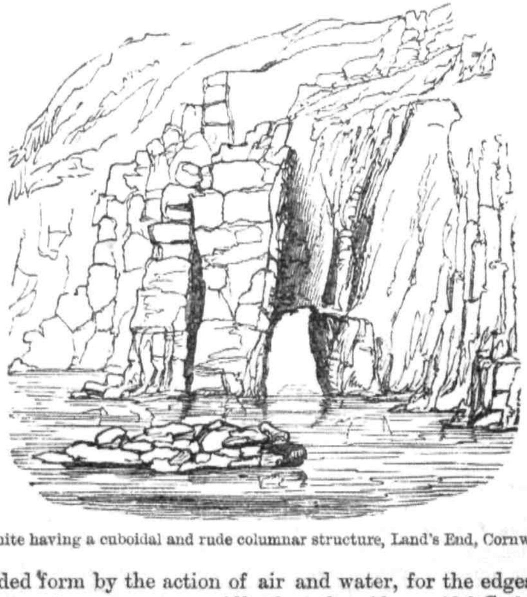
Fig. 607.



Mass of granite near the Sharp Tor, Cornwall.

stratified mass, as in the annexed figure, and sometimes like heaps of erratic boulders, for which they have been mistaken. The exterior of these stones, originally quadrangular, acquires a

Fig. 608.



Granite having a cuboidal and rude columnar structure, Land's End, Cornwall.

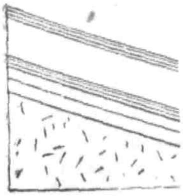
rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides. Although it is the general peculiarity of granite to assume no definite shapes,

it is nevertheless occasionally subdivided by fissures, so as to assume a cuboidal, and even a columnar, structure. Examples of these appearances may be seen near the Land's End in Cornwall. (See fig. 608.)

The foot of the granite having disintegrated, and much of it having been carried off by wind, rain, and sometimes streams, the highest point of the tallest tor or pinnacle represents the former level of the undenuded surface of the country, so that the present surface level on which the tor rests, has been the result of the denudation of ages. Other rocks have been worn away before the granite became visible, and it has become so by a vast process of natural uncovering. In the instance of the more or less central granites of mountain chains, the rock has participated in the movements which have crumpled and folded the crust of the earth, and have forced up deeply seated structures amidst great curvatures. Subsequently, enormous denudation has laid the rock bare. These remarks hold good for the other Plutonic rocks; and it must be understood that where any of them have been discovered, they present the appearances of having been forced upwards as intrusive masses or veins. The original rock underlying everything else, has not been traced in position, and granitic veins are found in the lowest visible rock masses.

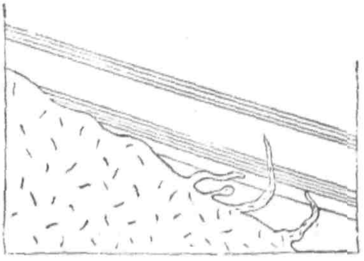
Granitic veins.—I have already hinted at the close analogy in the forms of certain granitic and trappean veins; and it will

Fig. 609.



Section as it would appear if the strata had been deposited on the granite.

Fig. 610.



Junction of granite and argillaceous schist in Glen Tilt. (MacMulloch.)

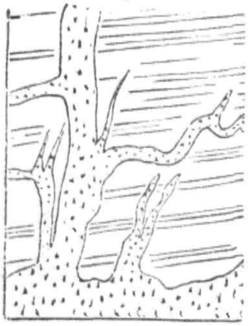
be found that strata penetrated by plutonic rocks have suffered changes very similar to those exhibited near the contact of volcanic dikes. Thus, in Glen Tilt, in Scotland, alternating strata of limestone and argillaceous schist come in contact with a mass of granite. The contact does not take place as might have been

looked for, if the granite had been formed there before the strata were deposited, in which case the section would have appeared as in fig. 609; but the union is as represented in fig. 610, the undulating outline of the granite intersecting different strata, and occasionally intruding itself in tortuous veins into the beds of clay slate and limestone, from which it differs so remarkably in composition. The limestone is changed in character by the proximity of the granitic mass or its veins, and acquires a more compact texture, like that of hornstone or chert, with a splintery fracture, and it effervesces slowly with acids.

The conversion of the limestone in these and many other instances into a siliceous rock, effervescing slowly with acids, would be difficult of explanation, were it not ascertained that such limestones are always impure, containing grains of quartz, mica, or felspar disseminated through them. The elements of these minerals, when the rock has been subjected to great heat, may have been fused, and so spread more uniformly through the whole mass. But besides, the siliceous matter may be introduced during the hydrothermal action which accompanied the intruding rocks.

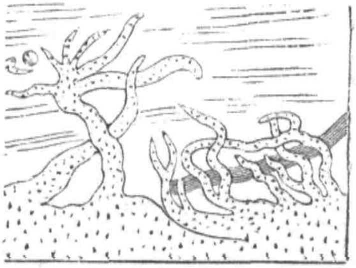
In the plutonic as in the volcanic rocks, there is every gradation from a tortuous vein to the most regular form of a

Fig. 611.



Granite veins traversing clay slate, Table Mountain, Cape of Good Hope.[2]

Fig. 612.



Granite veins traversing gneiss, Cape Wrath. (MacCulloch.)[3]

dike, such as intersect the tuffs and lavas of Vesuvius and Etna. Dikes of granite may be seen, among other places, on the southern flank of Mount Battock, one of the Grampians, the opposite walls sometimes preserving an exact parallelism for a

[2] Capt. B. Hall, Trans. Roy. Soc. Edinburgh, vol. vii.
[3] Western Islands, pl. 31.

considerable distance. As a general rule, however, granite veins in all quarters of the globe are more sinuous in their course than those of trap. They present similar shapes at the most northern point of Scotland, and the southernmost extremity of Africa, as the annexed drawings will show.

It is not uncommon for one set of granite veins to intersect another; and sometimes there are three sets, as in the environs of Heidelberg, where the granite, on the banks of the river Neckar, is seen to consist of three varieties, differing in colour, grain, and various peculiarities of mineral composition. One of these, which is evidently the second in age, is seen to cut through an older granite; and another, still newer, traverses both the second and the first. In Shetland there are two kinds of granite. One of them, composed of hornblende, mica, felspar, and quartz, is of a dark colour, and is seen underlying gneiss. The other is a red granite, which penetrates the dark variety everywhere in veins.[4]

Fig. 613 is a sketch of a group of granite veins in Cornwall, given by Messrs. Von Oeynhausen and Von Dechen.[5] The

Fig. 613.

Granite veins passing through hornblende slate, Carnsilver Cove, Cornwall.

main body of the granite is of a porphyritic appearance, with large crystals of felspar; but in the veins it is fine-grained, and without these large crystals. The general height of the veins is from 16 to 20 feet, but some are much higher.

The granites, syenites, diorites, felsites, and indeed all plutonic rocks, are frequently observed to contain metallic veins at or near their junction with stratified formations. On the

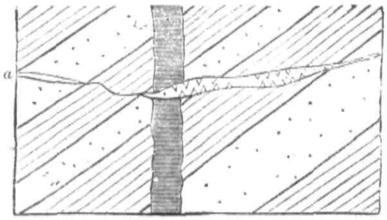
[4] MacCulloch, Syst. of Geol. vol. i. p. 58.

[5] Phil. Mag. and Annals, No. 27, New Series, March 1829.

other hand, similar veins which traverse stratified rocks are, as a general law, more metalliferous near such junctions than in other positions. Hence it has been inferred that these metals may have been spread in a gaseous form through the fused mass, and that the contact of another rock, in a different state of temperature, or sometimes the existence of rents in other rocks in the vicinity, may have caused the sublimation of the metals.[6]

Veins of pure quartz are often found in granite as in many stratified rocks, but they are not traceable, like veins of granite or trap, to large bodies of rock of similar composition. They appear to have been cracks, into which siliceous matter was infiltrated. Such segregation, as it is called, can sometimes clearly be shown to have taken place long subsequently to the original consolidation of the containing rock. Thus, for example, I observed in the gneiss of Tronstadt Strand, near

Fig. 614.



a, b. Quartz vein passing through gneiss and greenstone, Tronstadt Strand, near Christiania.

Drammen, in Norway, the annexed section on the beach. It appears that the alternating strata of whitish granitiform gneiss and black hornblende schist were first cut through by a greenstone dike, about 2½ feet wide; then the crack *a*, *b*, passed through all these rocks, and was filled up with quartz. The opposite walls of the veins are in some parts incrusted with transparent crystals of quartz, the middle of the vein being filled up with common opaque white quartz.

When masses of granite approach, or are visible at the surface of the earth, their relations to the strata and rocks on all sides, and above, are often very difficult to understand. The surrounding rocks are often greatly altered in their stratification and mineral nature.

In many localities there are great extensions of granite far below the surface, which have only become known by the

[6] Necker, Proceedings of Geol. Soc. vol. i. p. 392, 1832.

coming up of veins to the surface and the alterations which have occurred in the rocks which have not yet been denuded off.

On the different ages of the Plutonic rocks.—It has been stated that the plutonic rocks were formed under greater pressure than the volcanic, and that the pressure could only have been produced by the gravitation of superincumbent strata or rocks, and by compression by contraction, with or without crust movement in grand curves. It is probable that a rock like granite in chemical composition, underlies the deepest known rocks, and that under special conditions it has been forced upwards, and has cooled and accepted the crystalline form. Although, theoretically, the volcanic rocks resemble the plutonic in their method of origin and habit, yet it must be remembered that the dolerites, diabases, and the modern lavas contain minerals, some of which are not found in granite, or syenite, or typical plutonic rocks. Again, there is no satisfactory instance of granite veins perforating strata lately formed (geologically).

Of course, a granite may have been uncovered, and deposition of strata of any age may have occurred upon it subsequently. Such strata, however, would not have been metamorphosed, nor would they be found intruded upon, by veins.

Test of age by relative position.—Unaltered fossiliferous strata of every age are met with reposing immediately on plutonic rocks; as at Christiania in Norway, where the Pleistocene deposits, and at Heidelberg on the Neckar, and Mount Sorrel in Leicestershire, where the New Red Sandstone formations rest on granite. In these, and similar instances, inferiority in position is connected with the superior antiquity of granite. The crystalline rock was solid before the sedimentary beds were superimposed, and the latter usually contain rounded pebbles of the subjacent granite.

Test by intrusion and alteration.—But when plutonic rocks are continued as veins in the sedimentary strata, and have altered them near the point of contact, it is clear that, like intrusive traps, they are newer than the strata which they have invaded and altered. Examples of the application of this test will be given in the sequel.

Test by mineral composition.—Sometimes a peculiar mineral condition of a plutonic rock prevails, and is found exclusively prevailing throughout an extensive region; so that, having ascertained the relative age of the rock in one place, we can recognise its identity in others, and thus determine from a single section the chronological relations of large mountain masses. Having observed, for example, that the syenite of

Norway, in which the mineral called zircon abounds, has altered the Silurian strata wherever it is in contact, we do not hesitate to refer other masses of the same zircon-syenite in the south of Norway to a post-Silurian date. But too much reliance should not be placed on mineral character as a test of age.

Test by included fragments.—This criterion can rarely be of much importance, because the fragments included in granite, are usually so much altered, that they cannot be referred with certainty to the rocks whence they were derived. In the White Mountains, in North America, according to Professor Hubbard, a granite vein, traversing granite, contains fragments of slate and trap which must have fallen into the fissure when the fused materials of the vein were injected from below, and thus the granite is shown to be newer than those slaty and trappean formations from which the fragments were derived.

Tertiary plutonic rocks.—At many different points in the Hebrides, as in Skye, Mull, Rum, St. Kilda, &c., great masses of granite and syenite are found in close association with the Tertiary volcanic rocks which have been before described.[7] Dr. MacCulloch described the syenites of Skye as intersecting limestone and shale which are of the age of the Lias. The limestone, which at a greater distance from the granite contains shells, exhibits no traces of them near its junction, where it has been converted into a highly crystalline marble.

MacCulloch pointed out that the granite and syenite here, as in Raasay, were newer than the secondary strata of these islands, and Professor A. Geikie afterwards showed that in Mull there are strong grounds for believing these granites and syenites to be of Tertiary age, like the volcanic rocks with which they are so intimately associated. Professor Zirkel, of Leipsic, has discovered that both in Mull and Skye there are great mountain masses of intrusive rocks, consisting of gabbro containing much olivine, which have been erupted subsequently to the granites. In Skye these gabbros constitute the remarkable Cuchullin Hills, which are so famed for their wild and majestic scenery. And lastly Professor Judd has shown that the great mountain groups in the Hebrides, composed of granites and gabbros, constitute the relics of five grand volcanoes which were in eruption during a great part of the Tertiary period, the earlier formed masses of granite, being connected with a series of felspathic lavas probably of Eocene age; while the gabbros, which break through the granites, are the consolidated reservoirs that gave rise to the great streams of basaltic lava of Oligocene age, which con-

[7] Judd, 'Ancient Volcanoes of the Highlands,' Quart. Jour. Geol. Soc. vol. xxx. p. 200, 1874.

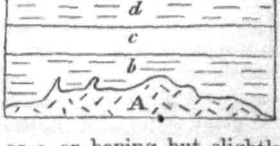
stitute the plateaux forming so large a portion of the Hebridean Archipelago. These researches show that the Western Isles of Scotland afford a most admirable and instructive series of illustrations of the intimate connection between the rocks of the volcanic and the plutonic classes respectively; and at the same time of the perfect identity in their nature and sequence, of the phenomena of volcanic activity during former periods of the earth's history, and those which are exhibited to us at the present day. There are strong grounds for believing that the granites of Arran and the Mourne Mountains in Ireland are of the same age as those of Skye, Mull, Rum, &c.

In a former part of this volume (p. 237), the great Nummulitic formation of the Alps and Pyrenees was referred to the Eocene period, and it follows that vast movements which have raised those fossiliferous rocks from the level of the sea to the height of more than 10,000 feet above its level have taken place since the commencement of the Tertiary epoch. Here, therefore, if anywhere, we might expect to find hypogene formations of Eocene date breaking out in the central axis or most disturbed region of the loftiest chain in Europe. It was believed, and is still credited by some geologists, that in the Swiss Alps, even the *flysch*, or upper portion of the nummulitic series, has been occasionally invaded by plutonic rocks, and converted into crystalline schists of the hypogene class. It is stated that even the talcose granite or gneiss of Mont Blanc itself has been in a fused or pasty state since the *flysch* was deposited at the bottom of the sea; and the question as to its age is not so much whether it be a secondary or tertiary granite or gneiss, as whether it should be assigned to the Eocene or Miocene epoch.

But the student must be cautioned against receiving most of the statements regarding the Tertiary age of granites in disturbed areas, such as those of mountain-chains. For inversions of strata are exceedingly common, and on a very gigantic scale.

Plutonic rocks of Cretaceous Period.—It will be shown in the next chapter that the Chalk and the Lias have been altered by granite in the eastern Pyrenees. Whether such granite be Cretaceous or Tertiary cannot easily be decided. Suppose *b*, *c*, *d*, fig. 615, to be three members of the Cretaceous series, the lowest of which, *b*, has been altered by the granite A, the modifying influence not having extended so far as *c*, or having but slightly affected its lowest beds. Now it can rarely be possible for the

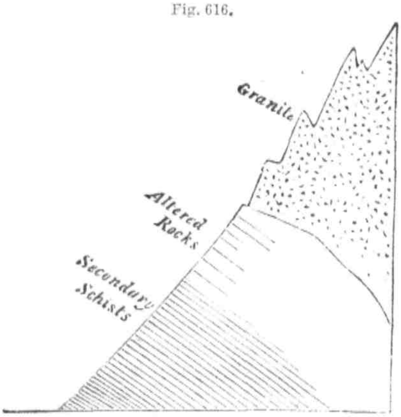
Fig. 615.



geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*. But as some Cretaceous and even Tertiary rocks have been raised to the height of more than 9,000 feet in the Pyrenees, we must not assume that plutonic formations of the same periods may not have been brought up and exposed by denudation, at the height of 2,000 or 3,000 feet on the flanks of that chain.

Plutonic rocks of the Oolite and Lias.—In the Department of the Hautes-Alpes, in France, M. Élie de Beaumont traced a black argillaceous limestone charged with belemnites, to within a few yards of a mass of granite. Here the limestone begins to put on a granular texture, but is extremely fine-grained. When nearer the junction it becomes grey, and has a saccharoid structure. In another locality, near Champoleon, a granite composed of quartz, black mica, and rose-coloured felspar is observed partly to overlie the secondary rocks, producing an alteration which extends for about 30 feet downwards, diminishing in the beds which lie farthest from the granite. (See fig. 616.) In the altered mass the argillaceous beds are hardened, the limestone is saccharoid, the grits quartzose, and in the midst of them is a thin layer of an imperfect granite. It is also an important circumstance that near the point of contact, both the granite and the secondary rocks become metalliferous, and contain nests and small veins of blende, galena, iron, and copper pyrites. The stratified rocks become harder and more crystalline, but the granite, on the contrary, softer and less perfectly crystallised near the junction.[8] Although the granite is incumbent in the above section (fig. 616), we cannot assume that it overflowed the strata, for the disturbances of the rocks are so

Fig. 616.



Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

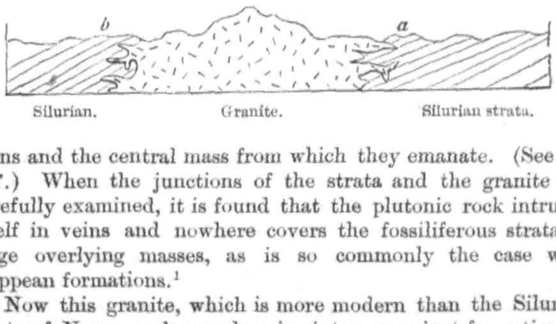
[8] Elie de Beaumont, Sur les Montagnes de l'Oisans, &c. Mém. de la Soc. d'Hist. Nat. de Paris, tom. v.

great in this part of the Alps that their original position is often inverted. Therefore the age of the granite is doubtful.

Plutonic rocks of Carboniferous Period.—The granite of Dartmoor, in Devonshire, was formerly supposed to be one of the most ancient of the plutonic rocks, but is now ascertained to be posterior in date to the Culm-measures of that county, which from their position, and as containing true coal-plants and Trilobites of the *Phillipsia* group, are now known to be members of the Carboniferous series. This granite has broken through the Devonian and Carboniferous stratified formations, the successive members of the Culm-measures abutting against the granite, and becoming metamorphosed as they approach it. These strata are also penetrated by granite veins, and dikes, called 'elvans.'[9] The granite of Cornwall is probably of the same date, and, therefore, as modern as the Carboniferous strata, if not newer.

Plutonic rocks of Silurian Period.—It has long been thought that a very ancient granite near Christiania, in Norway, is posterior in date to the Lower Silurian strata of that region, although its exact position in the Palæozoic series cannot be defined. Von Buch first announced, in 1813, that it was of newer origin than certain limestones containing Orthocerata and Trilobites. The proofs consist in the penetration of granite veins into the shale and limestone, and the alteration of the strata, for a considerable distance from the point of contact, both of these

Fig. 617.



Silurian. Granite. Silurian strata.

veins and the central mass from which they emanate. (See fig. 617.) When the junctions of the strata and the granite are carefully examined, it is found that the plutonic rock intrudes itself in veins and nowhere covers the fossiliferous strata in large overlying masses, as is so commonly the case with trappean formations.[1]

Now this granite, which is more modern than the Silurian strata of Norway, also sends veins into an ancient formation of gneiss of the same country; and the relations of the plutonic rock and the gneiss, at their junction, are full of interest when

[9] Proceed. Geol. Soc. vol. ii. p. 562; and Trans. 2nd ser. vol. v. p. 686.

[1] See the Gæa Norvegica and other works of Keilhau, with whom I examined this country.

geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*. But as some Cretaceous and even Tertiary rocks have been raised to the height of more than 9,000 feet in the Pyrenees, we must not assume that plutonic formations of the same periods may not have been brought up and exposed by denudation, at the height of 2,000 or 3,000 feet on the flanks of that chain.

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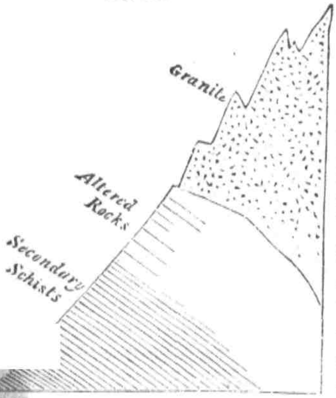

...unction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

... of quartz, black mica, and rose-coloured felspar is ...ed partly to overlie the secondary rocks, producing an ...on which extends for about 30 feet downwards, dimi... in the beds which lie farthest from the granite. (See ... In the altered mass the argillaceous beds are hardened, ...ne is saccharoid, the grits quartzose, and in the midst ...a thin layer of an imperfect granite. It is also an ...rcumstance that near the point of contact, both the ... the secondary rocks become metalliferous, and ...nd small veins of blende, galena, iron, and copper ...ratified rocks become harder and more crystal... ...ite, on the contrary, softer and less perfectly ...he junction.[8] Although the granite is incum... ...ection (fig. 616), we cannot assume that it ...a, for the disturbances of the rocks are so

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CHAPTER XXXII.

METAMORPHIC ROCKS.

Terms Metamorphic and Metamorphism applied to rocks—Local or contact metamorphism—Regional metamorphism—All classes of rocks subject to metamorphism—Influence of heat, pressure, chemical action—The origin of the heat—Pressure—Anomalies—Direction of the pressure—Movement—Causes—Origin of oldest metamorphic rocks—Theories of Von Lasaulx, Sterry Hunt, and others—The most metamorphosed rocks the oldest—Arguments for and against the theory—Chemical changes—Dolomite, red chalk—Local or contact metamorphism, further examples regarding fossiliferous and carbonaceous rocks—Geikie's summary of local effects—Volcanic rocks metamorphosed—Metamorphic rocks altered—Regional metamorphic rocks—Gneiss, Mica-schists, Clay-slate, Rhyolite, Talc-schist, Hornblende-schist, Quartzite, Hälleflinta, Porcellanite, Crystalline limestone—Metamorphosed granite—Gabbro—Diabase—Serpentines.

We have now considered all the classes of rocks, except the last group, which comprises those called Metamorphic, and which are the result of the metamorphism of the others. The term Metamorphic implies that rocks have undergone changes of chemical, mineralogical, and textural kinds, and that their internal construction and outward appearance no longer resemble those of the original rock. Such changes and alterations as are sufficient to produce a kind of metamorphism, may be studied at the present day in volcanic regions, such as Iceland, or near Naples. The flowing of lava over soil, or into little streams or small lakes, produces remarkable alterations in the clays, which it bakes with heat and infiltrates with siliceous solutions, altering them chemically and mechanically. Similar changes occurred under the same circumstances in the geological ages, and may be taken as examples of local or contact metamorphism. But on examining the rocks in the midst of great mountain chains, and on the flanks of very old hills, schists, slates, crystalline limestones, gneisses, serpentines, &c., are found in positions where originally horizontal rocks have been subjected to vast lateral pressure, to superincumbent weight, to heat and the action of percolating gases, and chemical solutions. Such rocks have undergone '*regional metamorphism.*'

Great extents of country have been thus altered. The mountains of North Wales, the Lake district, and the Alps exemplify the grand phenomena of metamorphism, much surpassed,

however, in intensity in the North-west Highlands, where this 'regional metamorphism' is fully developed. There are then two groups of metamorphic rocks; in one the rocks have been locally affected, and in the other they have been exposed to more general and diffused agencies. Therefore geologists consider metamorphic action as local and as regional.

It is perfectly certain that metamorphism is not restricted to one class of rocks alone, but that the sedimentary strata, volcanic rocks, and even the plutonic, have often been altered, and are now presented to us, in many instances, under very different aspects. The degree of metamorphism varies—it may be intense or very slight; and the kind of change appears to have depended upon the original mineralogy of the rock and of its surrounding strata, together with the amount of pressure, heat, and introduced chemical matters.

The amount of heat available was great (as it is now) in the production of local, or contact, metamorphism; pressure was not necessarily great, and the intensity of the chemical action of the escaping steam and water charged with gases, and minerals in solution, was enhanced by certain amounts of it.

In the instances of regional metamorphism, the amount of heat which influenced the rocks appears to have been very variable in amount. The researches into the amounts of underground temperature at the present day lead us to believe that at a depth of little more than 10,000 feet 212° F. would be registered; and as the internal heat has been conducted to and radiated from the surface of the earth since the beginning, it follows that a higher temperature existed at this depth in the earlier geological ages.

During the great movements to which the strata of regions now occupied by mountain chains have been subjected, subsidences of 10,000 feet were minor phenomena, and similar and even much greater downward movements happened, during the progressive collection of many deep sedimentary strata (for example, of the Carboniferous formation), on areas where there has not been great crushing or the upheavals requisite for the development of a mountain system. The questions arise, If rocks have been sunken down to within the range of the temperature mentioned, or even of a higher, how have they been influenced and metamorphosed? Have they invariably been altered? If not, why not? It appears that some rocks have been considerably modified under the circumstances, but others have not. Amongst the examples of unaltered strata are the limestones, grits, and Coal measures, deposits which have been sunken down many thousands of feet, yet the alterations have

been but slight. Mallet urged with great ability, that heat over and above that due to the primitive state of the earth, was developed during the motion of rocks by the curving, crushing, and lateral movements incident to the formation of mountains and highly disturbed areas. This extra amount of heat was doubtless of practical value, and it is a matter of common observation that highly contorted deep strata are usually the most metamorphosed. But it is not invariably the case that such strata have been greatly altered; and it must be admitted (as Sterry Hunt has very well urged upon geologists) that very greatly curved, crushed, reversed, and dislocated strata on the flanks of the Alps have been but little or not at all metamorphosed. In fact, the difficulties of explaining the comparatively minor metamorphism of the later rocks which are on the flanks of mountain chains which are very old, and have been the result of several consecutive crust movements, are almost insuperable.

The amount and duration of the pressure, whether it was from side to side, or from above downwards also, were important factors, especially when the influence of percolating chemical solutions is admitted to have been very great. Pressure and heat enhance chemical action, and solutions were doubtless circulated amongst the rocks under the influence of a pressure which antagonised the great temperature, and did not permit the flashing off into steam. The slow removal of minerals, and their re-deposition, the decomposition of such complicated minerals as the felspars and micas, and the inevitable presence of carbon dioxide, all caused by and also associated with heat and long-continued pressure, give a slight insight into this process, the modern examples of which are wanting. It is necessary to remark that the pressure accompanying metamorphic action was both lateral and from above downwards, and possibly occasionally from below upwards, in direction. Gneiss, which is a foliated rock, usually has its layers parallel with the plane of the original bedding; but most of the schistose rocks have been subjected to vast, intermittent, long lasting, lateral thrust, accompanied by pushing, over-rolling movements. Their original bedding is no longer visible; but cleavage planes have been developed perpendicular to the direction of the force, and also nearly to that of the original bedding planes. The fossils which were present before the movement began, are often found crushed and also deformed, squeezed obliquely, and as if they had been rolled, partially, on their long axes. The causes of the lateral pressure have been considered (p. 52), and it is very probable that it was more intense before secular cooling had persisted for a great time.

geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*. But as some Cretaceous and even Tertiary rocks have been raised to the height of more than 9,000 feet in the Pyrenees, we must not assume that plutonic formations of the same periods may not have been brought up and exposed by denudation, at the height of 2,000 or 3,000 feet on the flanks of that chain.

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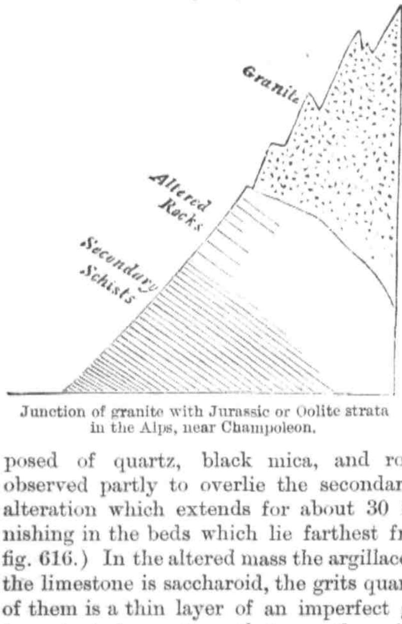
Fig. 616.



Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

[8] Elie de Beaumont, Sur les Montagnes de l'Oisans, &c. Mém. de la Soc. d'Hist. Nat. de Paris, tom. v.

So far as is known, all the most ancient rocks have been metamorphosed regionally, as well as locally in some places.

Hydrothermal action.—As all rocks contain water, it must have influenced their metamorphism under heat and pressure, and its agency would be enhanced by the presence of soluble minerals. In local metamorphism, water is introduced in excess from the intruding or overflowing volcanic rock, and also chemical matters in solution, and gases which decompose the surrounding strata. In regional metamorphism the excess of water does not appear to have been necessary, the original amount peculiar to the rocks probably being sufficient. But hydrothermal action—that is, the influence of hot water laden with mineral matter in solution, and also gases, especially carbon dioxide, in percolating rocks so heated, pressed, and having a certain amount of molecular movement—is recognised as the principal factor in metamorphism. There are many examples of the method of supply of hydrothermal agents.

Thus it is known that long after volcanoes have spent their force, hot springs continue to flow out at various points in the same area. In regions also subject to violent earthquakes such springs are frequently observed issuing from rents, usually along lines of fault or displacement of the rocks. These thermal waters are most commonly charged with a variety of mineral ingredients, and they retain a remarkable uniformity of temperature from century to century. A like uniformity is also persistent in the nature of the earthy, metallic, and gaseous substances with which they are impregnated. It is well ascertained that springs, whether hot or cold, charged with carbon dioxide, and with hydrofluoric acid, which is often present in small quantities, are powerful causes of decomposition and chemical reaction in rocks through which they percolate.

The changes which Daubrée has shown to have been produced by the alkaline waters of Plombières in the Vosges, are more especially instructive.[1] These waters have a heat of 160° F., or an excess of 109° above the average temperature of ordinary springs in that district. They were conveyed by the Romans to baths through long conduits or aqueducts. The foundations of some of their works consisted of a bed of concrete made of lime, fragments of brick, and sandstone. Through this and other masonry the hot waters have been percolating for centuries, and have given rise to various zeolites—Apophyllite and Chabazite among others; also to Calcareous spar, Arragonite, and Fluor-spar, together with siliceous minerals, such as Opal—all found

[1] Daubrée, Sur le Métamorphisme. Paris, 1860.

in the interspaces of the bricks and mortar, or constituting part of their re-arranged materials. The quantity of heat brought into action in this instance in the course of 2,000 years has, no doubt, been enormous, but the intensity of it, developed at any one moment, has been always inconsiderable.

From these facts and from the experiments and observations of Sénarmont, Daubrée, Delesse, Scheerer, Sorby, Sterry Hunt, and others, we are led to infer that when there are large volumes of matter in the earth, containing water and various acids intensely heated under enormous pressure, these subterranean fluid masses will gradually part with their heat by the escape of steam and various gases through fissures, producing hot springs; or by the passage of the same through the pores of the overlying and injected rocks. Even the most compact rocks may be regarded, before they have been exposed to the air and dried, in the light of sponges filled with water. According to the experiments of Henry, water, under an hydrostatic pressure of 96 feet, will absorb three times as much carbonic-acid gas as it can under the ordinary pressure of the atmosphere. There are other gases, as well as the carbonic acid, which water absorbs, and more rapidly in proportion to the amount of pressure. The water acts not only as a vehicle of heat, but also by its affinity for various silicates, which, when some of the materials of the invaded rocks are decomposed, form quartz, felspar, mica, and other minerals. As for quartz, it can be produced under the influence of heat by water holding alkaline silicates in solution, as in the case of the Plombières springs. The quantity of water required, according to Daubrée, to produce great transformations in the mineral structure of rocks, is very small. As to the heat required, silicates may be produced in the moist way at about incipient red heat, whereas to form the same in the dry way would require a much higher temperature.

M. Fournet, in his description of the metalliferous gneiss near Clermont, in Auvergne, states that all the minute fissures of the rock are quite saturated with free carbonic-acid gas; which gas rises plentifully from the soil there and in many parts of the surrounding country. The various elements of the gneiss, with the exception of the quartz, are all softened; and new combinations of the acid with lime, iron, and manganese are continually in progress.[2]

The power of subterranean gases is well illustrated by the stufas of St. Calogero in the Lipari Islands, where the horizontal

[2] See Principles, *Index*, 'Carbonated Springs,' &c.

strata of tuff forming cliffs 200 feet high have been discoloured in places by the jets of steam, often above the boiling point, called 'stufas,' issuing from the fissures; and similar instances are recorded by M. Virlet of corrosion of rocks near Corinth, and by Dr. Daubeny of decomposition of trachytic rocks by sulphuretted hydrogen and hydrochloric-acid gases in the Solfatara, near Naples. In all these instances it is clear that the gaseous fluids must have made their way through vast thicknesses of porous or fissured rocks, and their modifying influence may spread through the crust, for thousands of yards in thickness.

It has been urged as an argument against the metamorphic theory, that rocks have a small power of conducting heat, and it is true that when dry, and in the air, they differ remarkably from metals in this respect. The syenite of Norway has sometimes altered fossiliferous strata both in the direction of their dip and strike for a distance of a quarter of a mile. But in regions of metamorphism, the production of gneiss and mica and other schists was a slower process than local metamorphism, and the duration of the process compensated for the diminished increments of heat, pressure, and hydrothermal action. Professor Bischoff has shown what changes may be superinduced, on black marble and other rocks, by the steam of a hot spring, and we are becoming more and more acquainted with the prominent part which water is playing in distributing the heat of the interior through mountain masses of incumbent strata, and of introducing various mineral elements into them, in a fluid or gaseous state.

With regard to the origin of the undoubted oldest metamorphic rocks, there are several theories. Von Lasaulx considered that all the crystalline metamorphic rocks were derived from the wear and tear of the cooled granitic crust, whose sediments were modified by chemical action. Knop wrote that many kinds of plutonic rocks contributed to the materials of gneiss, mica-schist, &c., by the taking away of some minerals and elements, and the addition of others.

Sterry Hunt[3] states that 'the crystalline stratified rocks are not plutonic but neptunean in origin, and, except so far as they are mechanical sediments coming from the chemical or mechanical disintegration of more ancient rocks, were deposited as chemically formed sediments or precipitates in which the subsequent changes have been simply molecular, or at most confined to reactions, in certain cases, between the mingled elements of the sediments.'

[3] Chemical and Geological Essays. 1879.

Other geologists of great reputation believe that these crystalline schists and gneiss are metamorphosed sedimentary and other rocks, heat, pressure, and chemical action having been the agents. The application of the doctrine that the modern example must be sought in order to explain the ancient phenomena, is full of difficulty. For, as will be noticed farther on, the geological data on which comparatively modern regional metamorphism is asserted are full of doubt, and indeed have been contradicted by the latest authorities. Local metamorphism can be studied at the present time, but the question arises, Is it strictly logical to argue from it regarding regional changes? Modern research tends to the belief that the most metamorphosed rocks are the oldest, and that there is a sameness of mineral composition in altered rocks of the same age. But some of the most able geologists deny the truth of these propositions, assert that rocks of even Tertiary age have been highly metamorphosed regionally, and believe that the age of metamorphic rocks is not to be limited. That some highly metamorphic rocks are the oldest visible, such as the Laurentian gneiss of Canada, is beyond doubt, and it is evident that there are mica-schists and hornblende-schists, and other crystalline rocks, of age older than the Cambrian. One school of geologists restricts the highly metamorphosed rocks to this age. Another recognises very metamorphic rocks in the North-west Highlands, for instance, giving them a Lower Silurian age. In the Alps, the lowest sedimentary rocks are of Carboniferous age. Where are the other and preceding strata, which are well developed in many places on the European area? Represented by the metamorphic rocks, is the answer: they have been metamorphosed. On the southern side of the Himalayas, Tertiary rocks rest upon a vast thickness of metamorphic rocks, but on the north all the sedimentary series, from the Silurian to the Miocene inclusive, are found. Were these all the missing strata metamorphosed on the south? These are questions which the student will gradually understand, and he will recognise the difficulty of stating the truth definitely.

Besides local and regional metamorphism, the phenomena of which should be carefully kept separate, changes have occurred in rocks of all ages, and in those now forming, in which there has been more chemical than mechanical action. The formation of limestone into dolomite, the production of coal from vegetation, and the silicification of calcareous rocks and fossils, and the formation of red chalk, are familiar examples.

These might be termed simple chemical alterations in strata, but in the instance of dolomite the original limestone has

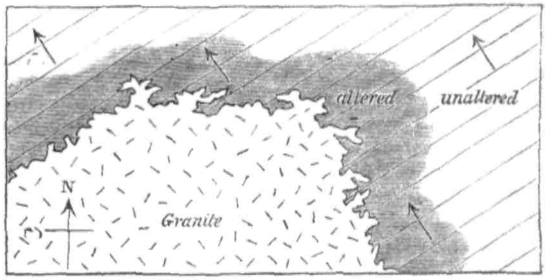
received peculiar powers of weathering, and in the process of silicification much destruction of structure is noticed. It is interesting to note that, although usually the result of agencies remote from local action, both of these processes may also be noticed close to volcanic dikes, and they were therefore elaborated by local metamorphism, and also by simple chemical action, remote from any extraordinary source of heat.

Local or contact metamorphism.—In treating of the nature of intrusive veins of volcanic and plutonic origin (p. 504), examples were given of alterations in the affected rocks, by heat and percolating water containing chemical matters. The subject was further illustrated in noticing the methods of distinguishing the age of volcanic rocks (p. 473). It is, therefore, only necessary to introduce a few instances of local metamorphism here.

Fossiliferous strata rendered metamorphic by intrusive masses of granite.—In the southern extremity of Norway there is a large district, on the west side of the fiord of Christiania, which I visited in 1837 with the late Professor Keilhau, in which hornblendic granite protrudes in mountain masses through fossiliferous strata, and usually sends veins into them at the point of contact. The stratified rocks, replete with shells and zoophytes, consist chiefly of shale, limestone, and some sandstone, and all these are invariably altered near the granite for a distance of from 50 to 400 yards. The aluminous shales are hardened, and have become flinty. Sometimes they resemble jasper. Ribboned jasper is produced by the hardening of alternate layers of green and chocolate-coloured schist, each stripe faithfully representing the original lines of stratification. Nearer the granite, the schist often contains crystals of hornblende, which are even met with in some places, for a distance of several hundred yards from the junction; and this black hornblende is so abundant that eminent geologists, when passing through the country, have confounded it with the ancient hornblende-schist, subordinate to the great gneiss formation of Norway. Frequently, between the granite and the hornblende-slate above mentioned, grains of mica and crystalline felspar appear in the schist, so that rocks resembling gneiss and mica-schist are produced. Fossils can rarely be detected in these schists, and they are more completely effaced in proportion to the more crystalline texture of the beds, and their vicinity to the granite. In some places the siliceous matter of the schist becomes a granular quartzite; and when hornblende and mica are added, the altered rock loses its stratification, and passes into a kind of granite. The limestone, which at points remote from the granite is of an earthy texture and blue colour, and often abounds in corals,

becomes a white granular marble near the granite, sometimes siliceous, the granular structure extending occasionally, upwards of 400 yards from the junction; the corals being for the most part obliterated, though sometimes preserved, even in the white marble. Both the altered limestone and hardened slate contain garnets in many places, also ores of iron, lead, and copper, with some silver. These alterations occur equally, whether the granite invades the strata in a line parallel to the general strike of the

Fig. 619.



Ground-plan of altered slate and limestone near granite, Christiania.
The arrows indicate the dip, and the oblique lines the strike of the beds.

fossiliferous beds, or in a line at right angles to their strike, both of which modes of junction will be seen by the accompanying ground plan (fig. 619).[4]

The granite of Cornwall sends forth veins into a coarse argillaceous schist, provincially termed killas. This killas is converted into hornblende-schist near the contact with the veins. These appearances are well seen at the junction of the granite and killas, in St. Michael's Mount, a small island nearly 300 feet high, situated in the bay, at a distance of about three miles from Penzance. The granite of Dartmoor, in Devonshire, says Sir H. De la Beche, has intruded itself into the Carboniferous slate and slaty sandstone, twisting and contorting the strata, and sending veins into them. Hence some of the slate rocks have become 'micaceous;' others more indurated, and with the characters of mica-slate and gneiss; while others again appear converted into a hard zoned rock strongly impregnated with felspar.[5]

Nowhere, however, are the phenomena of local metamorphism more beautifully illustrated than in the Western Isles of Scotland. Professor Judd has pointed out that in this neighbourhood great

[4] Keilhau, Gæa Norvegica, pp. 61–63.
[5] Geol. Manual, p. 479.

masses of granite and gabbro were thrust through the various Palæozoic and Secondary strata, during the Tertiary period, and that in the vicinity of the junctions of the igneous and the sedimentary masses, most instructive examples of metamorphism may be observed. Thus Lias limestones crowded with fossil shells are found losing, as we approach the igneous rocks, all traces of their organic remains, and at last passing into a highly crystalline or saccharoid marble suitable for statuary purposes. Clays and limestones, under like conditions, are also found to be deprived of every trace of the organic structures formerly in them and to graduate into indurated slaty rock and quartzite, while the felspathic sandstones of the Cambrian are altered to a highly micaceous schistose rock.

We learn from the investigations of M. Dufrénoy, that in the Eastern Pyrenees there are mountain masses of granite, posterior in date to the formations called Lias and Chalk of that district, and that these fossiliferous rocks are greatly altered in texture, and often charged with iron-ore, in the neighbourhood of the granite. Thus in the environs of St. Martin, near St. Paul de Fénouillet, the chalky limestone becomes more crystalline and saccharoid as it approaches the granite, and loses all trace of the fossils which it previously contained in abundance. At some points, also, it becomes dolomitic, and filled with small veins of carbonate of iron, and spots of red iron-ore.

The local metamorphism of Carbonaceous beds, such as coal-seams, is very interesting. The most simple result of the intrusion of a dike of basalt, for instance, amongst Coal-measures is for the coal to become hard and brittle, to lose its more volatile matters, and to turn to anthracite, and this change may take place 50 yards off. Close to the dike the coal may be perfectly destroyed, being in the form of cinder, and occupying a much smaller space than before; or, as in South Staffordshire, the coal may become sooty and coked. Professor A. Geikie remarks that the seams of coal present lines of easy escape of igneous matter coming from below, and the molten rock has usually flowed along the seams either above or below, or has even fissured and forced its way along their centre. He notices that[6] distillation arising from the destruction and alteration of coal and bituminous shales, caused the gases to find their way to the surface, and the liquid products to collect in fissures and cavities. Petroleum and asphalte are thus collected in chinks of sandstones and other sedimentary rocks, and of the igneous rocks themselves.

Prismatic structure resembling miniature basaltic columns has been produced in coal, by local metamorphic action,

[6] Geol. Manual, p. 176.

On the other hand, the trap has often been altered by contact with the coal, becoming white, yellow, earthy, light, and friable. This white trap has had its crystalline structure nearly destroyed and much of the lime and silica removed, and the iron remains as ferrous carbonate.

Professor A. Geikie summarises the effects of local metamorphism, and the following is an abstract of his views :[7]—

Groups of sedimentary strata have undergone an internal change, by which their usual lithological characters have been partially or wholly obliterated. The affected rock may be close to or two miles or more from the intrusive rock, whose subterranean surface may be entirely or partly hidden. The alteration *increases in intensity with greater proximity to the plutonic* rock, and must be regarded as the result of the presence of that rock. Bands of rock which have undergone minor changes are, however, found in the midst of highly altered portions. The character of the metamorphism depends fundamentally upon the composition and texture of the rock on which it has been effected. A thoroughly clastic (fragmental) rock may be transformed into a thoroughly crystalline one, with or without a perceptible alteration of the chemical composition. The crystalline character increases towards the limit of contact with the eruptive rock, and is accompanied by a progressive development of foliation, the minerals, more especially the mica, crystallising in folia, parallel either with the original stratification of the clastic mass, or with the cleavage surfaces, should these be its dominant divisional planes. In a note, Professor A. Geikie notices that in the South of Scotland the foliation around the granite bosses is coincident with stratification ; around Skiddaw, with cleavage. 'Along the line of contact,' he writes,[8] 'with granite, the foliation is sometimes excessively crumpled or puckered, while here and there the foliated structure disappears, and the rock assumes a lithological character, closely approximating to that of granite.' One point of importance in local metamorphism is the production of new minerals in rocks, besides their textural alteration. Silica has been found to have been very frequently introduced. Sedgwick noticed crystals of garnet along the edges of intruded basalt in Carboniferous limestone ; and in the neighbourhood of Botzen, where Permian or Triassic strata have been invaded by plutonic rock, they have become coarsely crystalline marble, and crystals of garnet, idocrase, spinel, &c., have been found in them and in the eruptive masses also. Volcanic rocks have been

[7] Op. cit. p. 581. [8] Op. cit. p. 582.

metamorphosed locally, and Scrope described the alteration of a trachyte conglomerate into a vitreous mass, by trachyte. Quartz-porphyry and diorite occasionally present examples of calcination and more or less complete fusion, and volcanic tuff and phonolite are found altered, presenting the aspect of pitchstone or obsidian on either side of dolerite dikes.

Metamorphic rocks have been altered locally, for in the North-west Highlands the metamorphic rocks are found, near their junction with the intrusive masses of the Grampian Mountains, to have undergone a further metamorphism of a local character.

Regional metamorphic rocks.—These rocks, when in their most characteristic development, are wholly devoid of organic remains, and contain no distinct fragments of other sedimentary rocks. Gneiss and mica-schist may be taken as the examples. But shales and schists containing fossils or their impressions, may be considered to be the least affected rocks. They sometimes break out in the central parts of mountain chains, but in other cases extend over areas of vast dimensions, occupying, for example, nearly the whole of Norway and Sweden, where, as in Brazil, they appear alike in the lower and higher grounds. However crystalline these rocks may become in certain regions, they never, like granite or trap, send veins into contiguous formations. In Great Britain, those members of the series which approach most nearly to granite in their composition, as gneiss, mica-schist, and hornblende-schist, are chiefly found in the country north of the rivers Forth and Clyde, North and South Wales, the Malverns, and Leicestershire.

Many attempts have been made to trace a general order of succession or superposition in the members of this family; clay-slate, for example, having been often supposed to hold invariably a higher geological position than mica-schist, and mica-schist to overlie gneiss. But although such an order may prevail throughout limited districts, it is by no means universal. To this subject, however, I shall again revert, when the chronological relations of the metamorphic rocks are pointed out. The mechanical peculiarities of these rocks are embraced by the terms cleavage, foliation.

We have seen that sedimentary rocks in the immediate proximity of great igneous intrusions, are found to have undergone great induration, while the development of various crystalline minerals has frequently taken place along their planes of bedding. The similarity of the rocks thus formed, to many of the foliated or schistose rocks, characteristic of regional metamorphism, suggests that the latter may have been, in all cases, produced from pre-existing strata, by the action of analogous

chemical forces, operating on a more extended scale. Thus gneiss and mica-schist may be nothing more than altered micaceous and argillaceous sandstones, granular quartzite may have been derived from siliceous sandstone, and compact quartzite may be the last stage of alteration of the same materials. Similarly, clay-slate may be altered shale, and granular marble may have originated in the form of ordinary limestone, replete with shells and corals, which have since been obliterated; and, lastly, calcareous sands and marls may have been changed into impure crystalline limestones.

The anthracite and plumbago associated with regional metamorphic rocks may have been coal; for not only is coal converted into anthracite in the vicinity of some trap dikes, but we have seen that a like change has taken place generally even far from the contact of igneous rocks, in the disturbed region of the Appalachians. At Worcester, in the State of Massachusetts, 45 miles due west of Boston, a bed of plumbago and impure anthracite occurs, interstratified with mica-schist. It is about 2 feet in thickness, and has been made use of both as fuel and in the manufacture of lead pencils. At the distance of 30 miles from the plumbago, there occurs, on the borders of Rhode Island, an impure anthracite in slates containing impressions of coal-plants of the genera *Pecopteris*, *Neuropteris*, *Calamites*, &c. This anthracite is intermediate in character between that of Pennsylvania and the plumbago of Worcester, in which last the gaseous or volatile matter (hydrogen, oxygen, and nitrogen) is to the carbon only in the proportion of 3 per cent. After traversing the country in various directions, I came to the conclusion that the Carboniferous shales or slates with anthracite and plants, which in Rhode Island often pass into mica-schists, have at Worcester assumed a perfectly crystalline and metamorphic texture; the anthracite having been nearly transmuted into that state of pure carbon which is called plumbago or graphite.

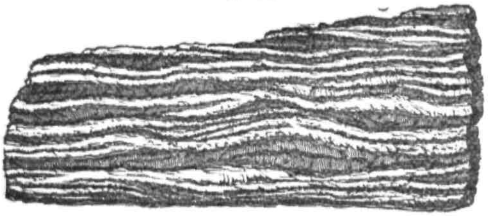
Now the alterations above described as superinduced in rocks by volcanic dikes and granite veins, prove incontestably that powers exist in nature capable of transforming fossiliferous into crystalline strata, a very few simple elements constituting the component materials not common to both classes of rocks.

Principal metamorphic rocks.—The following may be enumerated as the principal members of the metamorphic class:—

Gneiss.—The first of these, gneiss, may be called stratified —or by those who object to that term, foliated—granite, being formed of the same materials as granite—namely, orthoclase felspar, quartz, and mica in folia. In the specimen here figured, the white layers consist almost exclusively of granular felspar,

with here and there a speck of mica and grain of quartz. The dark layers are composed of grey quartz and black mica, with occasionally a grain of felspar intermixed. The rock splits most easily in the plane of these darker layers, and the surface thus exposed is almost entirely covered with shining spangles of mica. The accompanying quartz, however, greatly predominates in quantity, but the most ready cleavage is determined by the

Fig. 620.



Fragment of gneiss, natural size; section made at right angles to the planes of foliation.

abundance of mica in certain parts of the dark layer. Sometimes instead of consisting of these thin laminæ, gneiss is simply divided into thick beds, in which the mica has only a slight degree of parallelism to the planes of stratification.

It is then very undistinguishable from granite, affording an argument in favour of those geologists who regard all granite and syenite not as igneous rocks, but as aqueous formations so altered as to have lost all signs of their original stratified arrangement. The term Granitoid Gneiss is employed for these specimens.

Some gneisses, on the contrary, are very fissile. Accessory minerals occur, and some of them give the name to the kind of gneiss; the commonest are hornblende, tourmaline, garnet, apatite, and sometimes one or other of the usual minerals may be in excess, notably mica. Hence there are hornblendic gneiss and mica gneiss. When the mica is absent, or nearly so, garnet being present or not, the rock is called Granatite, and the red and milky-white folia of the Malvern kinds are very beautiful. Garnet rock, kyanite rock, and other gneisses are characterised by special accessory minerals. The distinction of gneiss and granite is maintained by most geologists, and the rocks differ in their method of origin. Gneiss is never found as an eruptive rock, all examples being of granite which has been subject to pressure. Granite is occasionally intrusive in gneiss, and includes masses of it. Protogine, a massive variety of gneiss, is the so-called granite of the Alps. It has had its magnesian mica altered so as to resemble talc.

Mica-schist, or *Micaceous schist*, is, next to gneiss, one of the most abundant rocks of the metamorphic series. It is slaty, essentially composed of mica and quartz, the mica sometimes appearing to constitute the whole mass. This rock passes by insensible gradations into other schistose rocks; by the addition of felspar it merges into gneiss, and by loss of quartz and increase of chlorite it passes into chlorite schist. The mica is usually Muscovite (potash mica), but biotite or magnesian mica may occur. It is in wavy laminæ of thin plates, and occurs as spangles, or as continuous plates, and the rock usually splits open along the micaceous folia. The quartz may be granular, and the microscope detects grains of quartz sand. Sorby has seen indications of ripple marks. Beds of pure quartz also occur in this formation. In some districts, garnets in regular twelve-sided crystals form an integrant part of mica-schist.

Clay-slate — Argillaceous schist — Argillite — Phyllite.—This rock sometimes resembles an indurated clay or shale. It is for the most part extremely fissile, often affording good roofing slate. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies from greenish or bluish-grey to a lead colour; and it may be said of this, more than of any other schist, that it is common to the metamorphic and fossiliferous series, for some clay-slates taken from each division would not be distinguishable by mineral characters alone.

Chlorite-schist is a green slaty rock, in which chlorite is abundant in foliated plates, usually blended with minute grains of quartz, or sometimes with felspar or mica; often associated with, and graduating into, gneiss and clay-slate.

Talc-schist is a foliated rock, in which the mineral talc predominates. It may contain felspar and quartz, and usually has an unctuous feel and a white or greenish colour. It must not be mistaken for a rock with a hydrous mica. *Epidote-schist* is a foliated rock containing a large amount of the mineral after which it is named.

Hornblende-schist is usually black, and composed principally of hornblende, with a variable quantity of felspar, and sometimes grains of quartz. When the schistose character disappears, the rock may be termed hornblende rock or amphibolite.

Actinolite-schist is a slaty foliated rock, composed chiefly of actinolite, an emerald-green mineral (allied to hornblende), which occurs in slender prismatic crystals, sometimes forming radiating groups, with some admixture of quartz, mica, and garnet.

Quartzite, although not a schistose rock, is frequently associated with schists, and is a granular to compact mass of quartz, white, yellow, or red, with a lustrous fracture. It occurs in masses, and gives a finely granular appearance to the naked eye, and the microscope reveals that it was quartz sand, cemented by a siliceous cement so as to abolish more or less the individuality of the grains. It occurs near dikes as a local metamorphism, and also as the result of regional alterations. *Schistose quartzite* is quartzite with mica capable of being split into flags.

Hälleflinta is composed of quartz and felspar, and is compact, breaking with a splintery fracture. The colour varies from grey, yellow, green, to black, and mica and chlorite are sometimes present. It may be altered felsite.

Porcellanite and *Argillite* are close-grained flinty or jaspery rocks produced by the induration or partial fusion of clay, and are generally red or green in colour. *Lydian stone*, a black or brownish rock, often containing crystalline grains of quartz, is the result of the metamorphism of carbonaceous shale.

Crystalline or *Metamorphic limestone.*—This rock, called by the earlier geologists *primary limestone*, is sometimes a white crystalline granular marble, which when in thick beds can be used in sculpture; but more frequently it occurs in thin beds, forming a foliated schist much resembling, in colour and arrangement, certain varieties of gneiss and mica-schist. When it alternates with these rocks, it often contains some crystals of mica, and occasionally quartz, felspar, hornblende, talc, chlorite, garnet, and other minerals. It enters sparingly into the structure of the metamorphic districts of Norway, Sweden, and Scotland, but is largely developed in the Alps.

Most commonly noticed as the result of contact or local metamorphism, crystalline limestone is often included in regional metamorphism. The celebrated marble of Carrara is an altered limestone, to which late research gives a Carboniferous age.

Igneous rocks metamorphosed.—*Granite* has its mica and felspar replaced more or less by tourmaline, and in Luxulliamite, orthoclase is found in crystals, scattered in a matrix of quartz and schorl (black tourmaline).[9] *Schorl rock*, a mixture of quartz and tourmaline, is considered to be a modified granite. Chlorite and cassiterite may be added to the ordinary minerals of granite, and form a black rock called Zwitter rock. If the felspar has to a great extent disappeared, and the mica is lepidolite, the rock is called Greissen.

[9] Bonney in Jukes-Brown, Phys. Geol. p. 274.

Claystone is a more or less decomposed form of felstone, and probably *Hälleflinta* should be noticed here rather than where it is usually placed amongst the altered sedimentary rocks.

Gabbro sometimes suffered alteration, the felspar being converted into a hard white mineral allied to saussurite, and the diallage into hornblende. It is then called Hornblendic gabbro. Troktolite is an altered gabbro, the felspar being anorthite, and the diallage has been more or less converted into serpentine.

In most works, all the very old intrusive basalts and dolerites are properly called *Diabase*, for those rocks have been slightly modified during the long ages which have passed since their day of intrusion and flowing. A chloritic mineral has been developed. If their augite is converted into uralite, the rock is termed Uralite diabase. The formation of white trap has already been noticed. Volcanic tuffs undergo alterations, and when acidic are called porphyroid, and when basic schalstein; the rocks are more or less schistose.

Serpentine is an altered intrusive rock, originally a basalt, trap or dolerite, with olivine. Professor Bonney, after noticing that a number of rocks are improperly so termed, limits the serpentine to the type of those of the Lizard in Cornwall. A compact massive rock of dull brown, red, and green tints, in which glittering crystals of a certain variety of enstatite are frequently conspicuous. The serpentines mainly consist of silicate of magnesia, with iron oxides, and about 12 per cent. of water. Lastly, it is to be noticed that intrinsic mineral changes occur in granites, gneisses, and very old plutonic rocks, without much visible external change. The alteration of crystals of felspar into kaolin, the original shape remaining, is an example. The extreme of this process of replacement, is accompanied by considerable modification in the character of the rock and its destruction.

CHAPTER XXXIII.

METAMORPHIC ROCKS—*continued*.

Definition of slaty cleavage and joints—Mechanical theory of cleavage—Condensation and elongation of slate rocks by lateral pressure—Lamination of some volcanic rocks due to motion—Whether the foliation of the crystalline schists be usually parallel with the original planes of stratification—Examples in Norway and Scotland—Causes of irregularity in the planes of foliation.

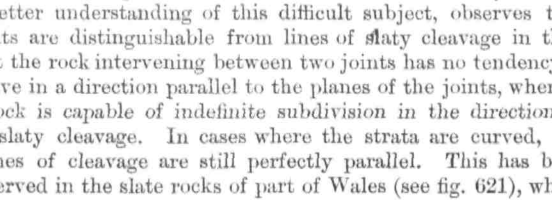
We have already seen that physical energies have frequently acted with great intensity upon all classes of rocks long subse-

quently to their consolidation, and we may next inquire whether the component minerals of the altered rocks usually arrange themselves in planes parallel to the original planes of stratification, or whether, after metamorphism, they more commonly take up a different direction.

In order to estimate fairly, the merits of this question, we must first define what is meant by the terms cleavage and foliation in rocks.

Slaty cleavage.—Professor Sedgwick, whose essay 'On the Structure of Large Mineral Masses' first cleared the way towards a better understanding of this difficult subject, observes that joints are distinguishable from lines of slaty cleavage in this, that the rock intervening between two joints has no tendency to cleave in a direction parallel to the planes of the joints, whereas a rock is capable of indefinite subdivision in the direction of its slaty cleavage. In cases where the strata are curved, the planes of cleavage are still perfectly parallel. This has been observed in the slate rocks of part of Wales (see fig. 621), which

Fig. 621.



Parallel planes of cleavage intersecting curved strata. (Sedgwick.)

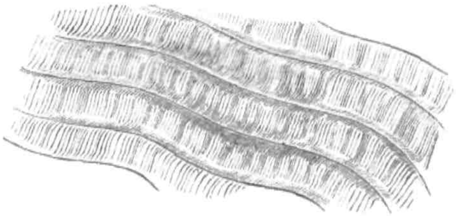
consist of a hard greenish slate. The true bedding is there indicated by a number of parallel stripes, some of a lighter and some of a darker colour than the general mass. Some stripes are found to be paralled to the true planes of stratification, wherever these are manifested by ripple marks, or by beds containing peculiar organic remains. Some of the contorted strata are of a coarse mechanical structure alternating with fine-grained crystalline chloritic slates, in which case the same slaty cleavage extends through the coarser and finer beds, though it is brought out in greater perfection in proportion as the materials of the rock are fine and homogeneous. It is only when these are very coarse that the cleavage planes entirely vanish. In the Welsh hills these planes are usually inclined at a very considerable angle to the planes of the strata, the average angle being as much as from 30° to 40°. Sometimes the cleavage planes dip towards the same point of the compass as those of stratification, but often to opposite points.[1] The cleavage, as represented in fig. 621, is generally constant over the whole of any area affected

[1] Geol. Trans. 2nd series, vol. iii. p. 461.

by one great set of disturbances, as if the same lateral pressure which caused the crumbling up of the rock along parallel, anti-clinal, and synclinal axes caused also the cleavage.

Professor McKenny Hughes remarks, that where a rough cleavage cuts flagstones at a considerable angle to the planes of stratification, the rock often splits into large slabs, across which the lines of bedding are frequently seen, but when the cleavage planes approach within about 15° of stratification, the rock is apt

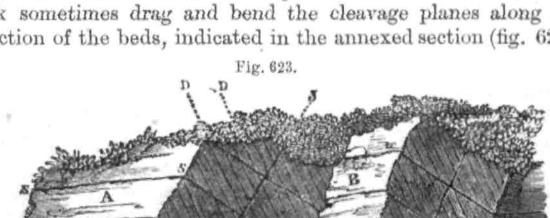
Fig. 622.



Section in Lower Silurian slates of Cardiganshire, showing the cleavage planes bent along the junction of the beds. (T. McK. Hughes.)

to split along the lines of bedding. He has also called my attention to the fact that subsequent movements in a cleaved rock sometimes drag and bend the cleavage planes along the junction of the beds, indicated in the annexed section (fig. 622).

Fig. 623.



Stratification, joints, and cleavage.
(From Murchison's 'Silurian System,' p. 245.)

The relation of cleavage planes to joints is seen in fig. 623. *The joints J J, are parallel. S S are the lines of stratification; D D are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.*

Mechanical theory of cleavage.—Professor Phillips has remarked that in some slaty rocks, affected by cleavage, the form of the outline of fossil shells and Trilobites has been much

changed by distortion, which has taken place in a longitudinal, transverse, or oblique direction. This change, he adds, seems to be the result of a 'creeping movement' of the particles of the rock along the planes of cleavage, its direction being always uniform over the same tract of country, and its amount in space being sometimes measurable, and being as much as a quarter or even half an inch.[2] Mr. D. Sharpe, following up the same line of inquiry, came to the conclusion that the present distorted forms of the shells in certain British slate rocks may be accounted for by supposing that the rocks in which they are embedded, have undergone compression in a direction perpendicular to the planes of cleavage, and a corresponding expansion in the direction of the dip of the cleavage.[3]

It would appear that the pressure was at right angles to the original bedding, and that it was vast and somewhat intermittent.

Subsequently (1853) Mr. Sorby demonstrated the great extent to which this mechanical theory is applicable to the slate rocks of North Wales and Devonshire,[4] districts where the amount of change in dimensions can be tested and measured by comparing the different effects exerted by lateral pressure on alternating beds of finer and coarser materials. Thus, for example, in the accompanying figure (fig. 624) it will be seen that the sandy bed *d f*, which has offered greater resistance, has been sharply contorted, while the fine-grained strata, *a*, *b*, *c*, have remained comparatively unbent. The points *d* and *f* in the stratum *d f* must have been originally four times as far apart as they are now. They have been forced so much nearer to each other, partly by bending, and partly by becoming elongated in the direction of what may be called the longer axes of their contortions, and lastly, to a certain small amount, by condensation. The chief result has obviously been due to the bending; but, in proof of elongation, it will be observed that the thickness of the bed *d f* is now about four times greater in those parts lying in the main direction of the flexures than in a plane perpendicular to them; and the same bed exhibits cleavage-planes in the direction of the greatest movement, although they are much fewer than in the slaty strata above and below.

Above the sandy bed *d f*, the stratum *c* is somewhat disturbed, while the next bed *b* is much less so, and *a* not at all; yet all these beds, *c*, *b*, and *a*, must have undergone an

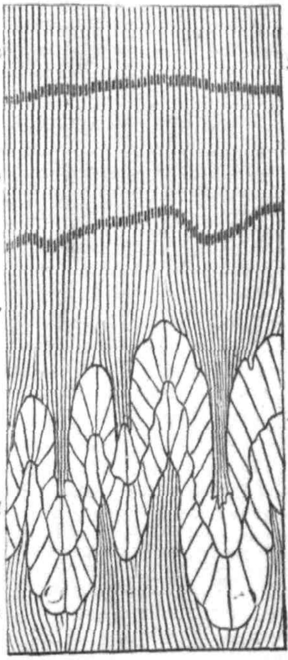
[2] Report, Brit. Assoc. Cork, 1843, Sect. p. 60.

[3] Quart. Journ. Geol. Soc. vol. iii. p. 87, 1847.

[4] On the Origin of Slaty Cleavage, by H. C. Sorby, Edinb. New. Phil. Journ. 1853, vol. lv. p. 137.

equal amount of pressure with *d*, the points *a* and *g* having approximated as much towards each other as have *d* and *f*. The same phenomena are also repeated in the beds below *d*, and might have been shown, had the section been extended downwards. Hence it appears that the finer beds have been squeezed into a fourth of the space they previously occupied, partly by condensation, or the closer packing of their ultimate particles (which has given rise to the great specific gravity of such slates), and partly by elongation in the line of the dip of the cleavage, of which the general direction is perpendicular to that of the pressure. 'These and numerous other cases in North Devon are analogous,' says Mr. Sorby, 'to what would occur if a strip of paper were included in a mass of some soft plastic material which would readily change its dimensions. If the whole were then compressed in the direction of the length of the strip of paper, it would be bent and puckered up into contortions, whilst the plastic material would readily change its dimensions without undergoing such contortions; and the difference in distance of the ends of the paper, as measured in a direct line or along it, would indicate the change in the dimensions of the plastic material.'

Fig. 624.



(Drawn by H. C. Sorby.)

Vertical section of slate rock in the cliffs near Ilfracombe, North Devon.

Scale one inch to one foot.

a, b, c, e. Fine-grained slates, the stratification being shown partly by lighter or darker colours, and partly by different degrees of fineness in the grain.

d, f. A coarser-grained, light-coloured sandy slate, with less perfect cleavage.

Mr. Sorby has come to the conclusion that the absolute condensation of the slate rocks amounts upon an average to about one-half their original volume. Most of the scales of mica occurring in certain slates examined by Mr. Sorby lie in the plane of cleavage; whereas in a similar rock not exhibiting cleavage

they lie with their longer axes in all directions. May not their position in the slates have been determined by the movement of elongation before alluded to? To illustrate this theory, some scales of oxide of iron were mixed with soft pipeclay in such a manner that they inclined in all directions. The dimensions of the mass were then changed artificially to a similar extent to what has occurred in slate rocks, and the pipeclay was then dried and baked. When it was afterwards rubbed *to a flat surface, perpendicular to the pressure, and in the line* of elongation, or in a plane corresponding to that of the dip of cleavage, the particles were found to have become arranged in the same manner as in natural slates, and the mass admitted of easy fracture into thin flat pieces in the plane alluded to, *whereas it would not yield in that perpendicular to the* cleavage.[5]

Dr. Tyndall, when commenting in 1856 on Mr. Sorby's experiments, observed that pressure alone is sufficient to produce cleavage, and that the intervention of plates of mica or scales of oxide of iron, or any other substances having flat surfaces, is quite unnecessary. In proof of this he showed experimentally that a mass of 'pure white wax, after having been submitted to *great pressure, exhibited a cleavage more clean than that of any* slate-rock, splitting into laminæ of surpassing tenuity.'[6] He remarks that every mass of clay or mud is divided and subdivided by surfaces among which the cohesion is comparatively small. On being subjected to pressure, such masses yield and spread out in the direction of least resistance, small nodules become converted into laminæ separated from each other by surfaces of weak cohesion, and the result is that the mass cleaves at right angles to the line in which the pressure is exerted. In further illustration of this, Professor Hughes remarks that concretions which in the undisturbed beds have their longer axes parallel to the bedding are, where the rock is much cleaved, frequently found flattened laterally, so as to have their longer axes parallel to the cleavage planes and at a considerable angle, even right angles, to their former position.

Mr. Darwin attributes the lamination and fissile structure of volcanic rocks of the trachytic series, including some obsidians in Ascension, Mexico, and elsewhere, to their having moved when liquid in the direction of the laminæ. The zones consist sometimes of layers of air-cells drawn out and lengthened in the supposed direction of the moving mass.[7]

[5] Sorby, as cited above, p. 741 note.

[6] Tyndall, View of the Cleavage of Crystals and Slate Rocks.

[7] Darwin, Volcanic Islands, pp. 69, 70.

Foliation of Crystalline Schists.—After studying, in 1835, the crystalline rocks of South America, Mr. Darwin proposed the term *foliation* for the laminæ or plates into which gneiss, mica-schist, and other crystalline rocks are divided. Cleavage, he observes, may be applied to those divisional planes which render a rock fissile, although it may appear to the eye quite or nearly homogeneous. Foliation may be used for those alternating layers or plates of different mineralogical nature of which gneiss and other metamorphic schists are composed.

That the planes of foliation of the crystalline schists in Norway accord very generally with those of original stratification is a conclusion long since espoused by Keilhau.[8] Numerous observations made by Mr. David Forbes in the same country (the best probably in Europe for studying such phenomena on a grand scale) confirm Keilhau's opinion. In Scotland, also, Mr. D. Forbes has pointed out a striking case where the foliation is identical with the lines of stratification in rocks well seen near Crianlarich on the road to Tyndrum, about 8 miles from Inverarnan in Perthshire. There is in that locality a blue limestone, foliated by the intercalation of small plates of white mica, so that the rock is often scarcely distinguishable in aspect from gneiss or mica-schist. The stratification is shown by the large beds and coloured bands of limestone all dipping, like the folia, at an angle of 32 degrees N.E.[9] In stratified formations of every age we see layers of siliceous sand with or without mica, alternating with clay, with fragments of shells or corals, or with seams of vegetable matter, and we should expect the mutual attraction of like particles to favour the crystallisation of the quartz, or mica, or felspar, or carbonate of lime along the planes of original deposition, rather than in planes placed at angles of 20 or 40 degrees to those of stratification.

After a general examination of the metamorphic rocks of the Highlands, Sir Roderick Murchison and Mr. Geikie were led to the conclusion that throughout the whole district foliation is coincident with the stratification of the rocks, and not, as had been suggested by Mr. Daniel Sharpe, with their cleavage.[1] Mr. Scrope, on the other hand, is inclined to attribute the foliation of the crystalline schists to 'the results of internal differential movements in the constituents of the subterranean mineral matter while exposed to enormous irregular pressures as well as variations of temperature, and under these influences changing at times from a solid to a fluid state and probably

[8] Norske Mag. Naturvidsk. vol. i. p. 71.

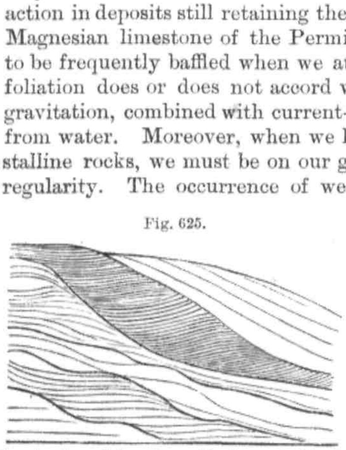
[9] Quart. Journ. Geol. Soc. vol. xi. p. 166. 1855.

[1] Quart. Journ. Geol. Soc. vol. xvii. 1861, p. 232.

back again to crystalline solidity, through intervening phases of viscosity—movements and changes which must *of necessity* have frequently arranged and rearranged the component crystalline minerals, sometimes in irregular composition like that of granite, diorite, or trachyte, sometimes in laminar or schistose bands like those of gneiss, mica-schist, and other so-called metamorphic crystallines.'[2]

We have seen how much the original planes of stratification may be interfered with or even obliterated by concretionary action in deposits still retaining their fossils, as in the case of the Magnesian limestone of the Permian. Hence we must expect to be frequently baffled when we attempt to decide whether the foliation does or does not accord with that arrangement which gravitation, combined with current-action, imparted to a deposit from water. Moreover, when we look for stratification in crystalline rocks, we must be on our guard not to expect too much regularity. The occurrence of wedge-shaped masses, such as belong to coarse sand and pebbles — diagonal lamination— ripple-marked— unconformable stratification—the fantastic folds produced by lateral pressure — faults of various width—intrusive dikes of trap — organic bodies of diversified shapes — and other causes of unevenness in the planes of deposition, both on the small and on the large scale, will interfere with parallelism. If complex and enigmatical appearances did not present themselves, it would be a serious objection to the metamorphic theory. Mr. Sorby has shown that the peculiar structure belonging to ripple-marked sands, or that which is generated when ripples are formed during the deposition of the materials, is distinctly recognisable in many varieties of mica-schists in Scotland.[3]

Fig. 625.



Lamination of clay-stone, Montagne de Séguinat, near Gavarnie, in the Pyrenees.

In the preceding diagram I have represented carefully the lamination of a coarse argillaceous schist which I examined in 1830 in the Pyrenees. In part it approaches in character to a green and blue roofing-slate, while part is extremely quartzose, the whole mass passing downwards into micaceous schist. The

[2] Scrope, Volcanoes, 1872, preface, p. 18; and Geologists' Mag. vol. i. p. 361.

[3] H. C. Sorby, F.R.S. Quart. Journ. Geol. Soc. vol. xix. p. 401.

vertical section here exhibited is about 3 feet in height, and the layers are sometimes so thin that fifty may be counted in the thickness of an inch. Some of them consist of pure quartz. There is a resemblance in such cases to the diagonal lamination which we see in sedimentary rocks, even though the layers of quartz and of mica, or of felspar and other minerals, may be more distinct in alternating folia than they were originally.

CHAPTER XXXIV.

THE DIFFERENT AGES OF METAMORPHIC ROCKS.

Difficulty of ascertaining the age of metamorphic strata—The two schools of metamorphism—Greater accuracy of surveying, and greater petrological knowledge required—Regional metamorphism stated to be of different ages, and even to be of Tertiary date by one school—Stated to be mainly Archæan, and not Post-Palæozoic, by the other—Regional metamorphism in the Alps, Himalayas, Apennines, and North-west of Scotland—Sameness of hypogene and regionally metamorphosed rocks.

According to theory, the metamorphic rocks have been deposited during one period, and have become altered, mechanically and chemically, subsequently. We can rarely hope to define with exactitude the date of deposition and alteration, or invariably to appreciate the time which elapsed between the phenomena. If we rely upon fossil evidence, it is clear that the organic remains may have been destroyed. Superposition itself is an ambiguous test, especially when we desire to determine the period of crystallisation. For, as metamorphism occurs mainly in disturbed districts, and invariably when the disturbance has been great, the normal sequence of rocks and strata has been perverted, and is often not to be recognised.

The mineral character of the altered rocks affords a glimpse of the required truth to some geologists, but not to others, because one school of advanced petrological science insists that the massive gneisses and extremely schistose, micaceous, and hornblendic rocks are the oldest, whilst another teaches that they may be of Silurian, Devonian, and even of Secondary and Tertiary age. Again, care must be taken not to confuse local or contact metamorphism with regional metamorphism. The age of the local metamorphism of a stratum depends, of course, upon that of the intrusive or flowing igneous rock, and the method by which this may be estimated has been considered already.

When discussing the ages of the igneous rocks, we have seen that examples occur of various primary, secondary, and tertiary deposits converted into metamorphic strata near their contact with granite. There can be no doubt in these cases that strata, once composed of mud, sand, and gravel, or of clay, marl, and shelly limestone, have for the distance of several yards, and in some instances several hundred feet, been turned into gneiss, mica-schist, hornblende-schist, chlorite-schist, quartz-rock, and statuary marble. It may be easy to prove the identity of two different parts of the same stratum—one where the rock has been in contact with a volcanic or plutonic mass, and has been changed into marble or hornblende-schist, and another not far distant, where the same bed remains unaltered and fossiliferous.

But in the instances of regional metamorphism extending over hundreds of square miles, and including parts of mountain-chains, the difficulty of deciding the age of the metamorphism is great. Greater accuracy of details is required, and more careful geological surveying is absolutely necessary, before the two opposite theories of the age of regional metamorphism can be satisfactorily settled. Formerly, as already hinted, it was universally believed that any form of metamorphism or intensity of metamorphic action could occur at any geological period, and that it was not unreasonable to credit that changes of a hypogene character were now progressing.

But it is taught by some very distinguished geologists that regional metamorphism of a decided character, exhibiting gneisses and extremely schistose rocks, was palæozoic at the latest, and that much of it happened before the fossiliferous strata were laid down. Modified metamorphism of a regional character occurred later, but still not in the Mesozoic ages. It is denied that igneous rocks graduate into the metamorphic, and it is asserted by this school of geologists that the beliefs of its antagonists are founded upon ill-observed details, and upon the confusing of local and regional metamorphism.

With regard to the first theory, all the results of the study of great mountain masses in the first half of this century tended to prove its truth. But more accurate observation, and more careful surveying, has decided against the Mesozoic and Tertiary age of some metamorphic rocks. At the same time it is true that admirable field work has left the question of the early or late date of metamorphism unsettled in some of the most important districts in the world—for instance, the North-west Highlands and the Himalayas.

The existence of rocks in mountain masses of Palæozoic, Secondary, and even of Eocene age, metamorphosed into cry-

stalline schists, has been asserted over and over again in the Alps. A very remarkable paper on the Geology of the Alps, by Murchison, in 1848,[1] refers to the Pass of Martinsloch, in Glarus, 8,000 feet above sea-level. In this locality, nummulitic beds dipping S.S.E., at a high angle, are regularly overlaid by the succeeding sandstone Flysch, resting unconformably and in a nearly horizontal attitude, upon the edges of which are 150 feet of hard Jurassic limestone, overlaid in its turn by *talcose* and *micaceous schists*, which were regarded by Escher as similar to those which underlie these limestones in the valley below. The mass of Flysch appears nearly to dip beneath these limestones, which in their turn are overlaid by Neocomian and Cretaceous strata. The superposition of the schists was not original, but has been brought about by fracture and displacement along an anticlinal. Similar great inversions are seen in the Valley of Chamounix, where secondary limestones dip at a high angle toward Mont Blanc, and plunge beneath its crystalline schists. Similar inversions occur in the Pyrenees.

In one of the sections described by M. Studer in the highest of the Bernese Alps, namely, in the Roththal, a valley bordering the line of perpetual snow on the northern side of the Jungfrau, there occurs a mass of gneiss 1,000 feet thick, and 15,000 feet long, which I examined, not only resting upon, but also again covered by strata containing oolitic fossils. These anomalous appearances may partly be explained by supposing great solid wedges of intrusive gneiss to have been forced in laterally between strata to which I found them to be in many sections unconformable. The superposition also of the gneiss to the oolite may be due to a reversal of the original position of the beds in a region where the contortions have been on so stupendous a scale.

Professor Favre, of Geneva, to whom we owe so much correct knowledge regarding the Alps, traces the origin of Mont Blanc from a time when palæozoic rocks of Carboniferous age, with their beds of coal and plant remains, were deposited upon a partially submerged region of gneiss and crystalline schists. Many of the strata contain the denuded remains of these schists. Some disturbance occurred, and the secondary rocks were laid down during subsidence, and finally the Nummulitic series of overlying sandstones. Then came the great movement of mountain making, and the strata and schists were curved, folded, faulted, inverted, and then schists were forced

[1] Quart. Journ. Geol. Soc. vol. v. p. 246.

above the reversed fossiliferous series. The results of the wear and tear of the mountain mass collected in the form of strata of gravels and clays on its flanks, and at last the final crush came, which added to the complication by inverting the last made strata on the flanks of the Alps so that they appear to dip underneath the Nummulitic group.

The student may ask, Where are the palæozoic rocks which should be found normally beneath the Carboniferous deposits? Have they not been changed into gneiss and schists?

The survey of the formation of the Himalayas, so ably performed by the Geological Survey of India, is full of difficulties in consequence of the remarkable positions of metamorphic and sedimentary rocks to the south and north of the chain respectively. Messrs. Medlicott and Blanford [2] notice that Stoliczka considered the oldest rock of the Himalayas to be a thick-bedded granitoid gneiss, with granitic intrusions. But there is now great hesitation in acknowledging a second and younger gneiss and schists which appear to represent a vast thickness of fossiliferous Palæozoic and Triassic strata, noticed to the north of the Central gneiss.

Northern Apennines—Carrara.—The celebrated marble of Carrara, used in sculpture, was once regarded as a type of primitive limestone. The absence of fossils, its mineral texture and composition, and its passage downwards into talc-schist and garnetiferous mica-schist, gave it a great age, especially as underlying gneiss, penetrated by granite veins, was believed to graduate into the schists. The variety of opinions regarding the age of this limestone which have been published by considerable authorities should warn the student against geological dogmatism. Seven distinguished geologists decided that the marble was an altered Oolitic limestone, and that the underlying schists are secondary in age and the result of plutonic action. It has been fairly proved since by Coquand [3] that the marble is of Carboniferous age, and the mind naturally refers to the reversals and foldings of the Alpine strata in explanation of the position of the crystalline schists.

The oldest stratified rock of Scotland is the hornblendic gneiss of Lewis, in the Hebrides, and that of the north-west coast of Ross-shire. It is the same as that intersected by numerous granite veins, which forms the cliffs of Cape Wrath, in Sutherlandshire, and is conjectured to be of Laurentian age. Above it lie unconformable beds of a reddish or purplish sandstone and conglomerate, nearly horizontal, and between 3,000

[2] Manual of the Geology of India, p. 596 *et seq.*
[3] Geol. Mag. July 1876.

and 4,000 feet thick. In these ancient grits no fossils have been found, but they are supposed to be of Cambrian date, for Sir R. Murchison found Lower Silurian strata resting unconformably upon them. These strata consist of quartzite with annelid burrows, and limestone in which Mr. Charles Peach was the first to find in 1854 three or four species of *Orthoceras*, also the genera *Cyrtoceras* and *Lituites*, two species of *Murchisonia*, a *Pleurotomaria*, a species of *Maclurea*, one of *Euomphalus*, and an *Orthis*. Several of the species are believed by Mr. Salter to be identical with Lower Silurian fossils of Canada and the United States. They are doubtless of Arenig age. Murchison, Sir A. Ramsay, and Professor A. Geikie have taught that all the gneisses and schists and other crystalline strata, seen to the eastward, which overlie the limestone and quartzite in question, are referable to some part of an altered or metamorphosed Silurian series.

These Scotch upper metamorphic strata are of gneiss, mica-schist, and clay-slate of vast thickness, and have a strike from north-east to south-west almost at right angles to that of the older Lewisian or Laurentian gneiss. The newest of the series is a clay-slate, on which, along the southern borders of the Grampians, the Lower Old Red, containing *Cephalaspis Lyellii*, *Pterygotus Anglicus*, and *Parka decipiens*, rests unconformably.

These statements are contradicted by many able geologists and petrologists who teach that the gneiss is either single or may be in two series, but that in either case the metamorphism was pre-Cambrian.

Metamorphic strata of older date than the Silurian and Cambrian rocks.—In Canada, the Lower Laurentian gneiss, quartzite, and limestone may be regarded as metamorphic, because among other reasons organic remains (*Eozoon Canadense*) have been detected in a part of one of the calcareous masses. The Upper Laurentian or Labrador series lies unconformably upon the Lower, and differs from it chiefly in having as yet yielded no fossils. It consists of gneiss with Labrador felspar and felstones, in all 10,000 feet thick, and both its composition and structure lead us to suppose that, like the Lower Laurentian, it was originally of sedimentary origin, and owes its crystalline condition to metamorphic action. The remote date of the period when some of these old Laurentian strata of Canada were converted into gneiss, may be inferred from the fact that pebbles of that rock are found in the overlying Huronian formation, which is probably of Pre-Cambrian age.

The metamorphic rocks of Pre-Cambrian age in England and Wales have been noticed.

Order of succession in metamorphic rocks.—It was remarked that, as the hypogene rocks, both stratified and unstratified, crystallise originally at a certain depth beneath the surface, they must always, before they are upraised and exposed at the surface, be of considerable antiquity, relatively to a large portion of the fossiliferous and volcanic rocks. Whether they were forming during all the geological periods is a debated question; but before any of them can become visible, they must be raised above the level of the sea, and some of the rocks which previously concealed them must have been removed by denudation. There is no universal and invariable order of superposition in metamorphic rocks, although a particular arrangement may prevail throughout countries of great extent.

But if we investigate different mountain-chains, we find gneiss, mica-schist, hornblende-schist, chlorite-schist, crystalline limestone, and other rocks, succeeding each other, and alternating with each other in every possible order. But the rule is that the thicker gneisses and most foliated schists are the oldest. It is, indeed, more common to meet with some variety of clay-slate forming the uppermost member of a metamorphic series than any other rock; but this fact by no means implies, as some have imagined, that all clay-slates were formed at the close of an imaginary period, when the deposition of the crystalline strata gave way to that of ordinary sedimentary deposits. Such clay-slates, in fact, are variable in composition, and sometimes alternate with fossiliferous strata, so that they may be said to belong almost equally to the sedimentary and metamorphic order of rocks. It is probable that had they been subjected to more intense plutonic action, they would have been transformed into hornblende-schist, foliated chlorite-schist, scaly talcose-schist, mica-schist, or other more perfectly crystalline rocks, such as are usually associated with gneiss.

Uniformity of mineral character in Hypogene Rocks.—It is true, as Humboldt has happily remarked, that when we pass to another hemisphere, we see new forms of animals and plants, and even new constellations in the heavens; but in the rocks we still recognise our old acquaintances—the same granite, the same gneiss, the same micaceous schist, quartz-rock, and the rest. There is certainly a great and striking general resemblance in the principal kinds of hypogene rocks, and of the regionally metamorphosed rocks in all countries, however different their ages.

CHAPTER XXXV.

MINERAL VEINS.

Different kinds of occurrence of ores, and mineral veins—Ordinary metalliferous veins or lodes—Their frequent coincidence with faults—Proofs that they originated in fissures in solid rock—Veins shifting other veins—Polishing of their walls or 'slicken-sides'—Shells and pebbles in lodes—Evidence of the successive enlargement and reopening of veins—Examples in Cornwall and in Auvergne—Dimensions of veins—Why some alternately swell out and contract—Filling of lodes by sublimation from below—Supposed relative age of the precious metals—Copper and lead veins in Ireland older than Cornish tin—Lead vein in Lias, Glamorganshire—Gold in Russia, California, Australia, and New Zealand—Origin of mineral veins.

THE manner in which metallic substances are distributed through the earth's crust, and more especially the phenomena of those more or less connected masses of ore called mineral veins, from which the larger part of the precious and other metals used by man is obtained, are subjects of the highest practical importance to the miner, and of no less theoretical interest to the geologist.

The metalliferous ores and other minerals which are of use to man may be noticed to occur in three manners. Some, such as the brown iron ore and clay ironstone of the Carboniferous formation, were formed contemporaneously with the deposits which contain them. They are interstratified, and are often in lenticular masses. In the Zechstein, copper was disseminated through the strata, probably at the time of their deposition. Other metalliferous ores occur in crystalline rocks and schists, for instance, beds of iron ore, iron pyrites, and auriferous pyrites. These were formed at the same time as the layers of quartz, mica, felspar, and other minerals, amongst which they lie. Besides these lenticular deposits, the rocks contain minerals diffused in their mass, such as Magnetite and Titaniferous iron in the basaltic rocks and diabases. The last method of distribution was by the introduction of ores and crystalline minerals, subsequent to the consolidation of the rocks, in cavities and fissures.

On different kinds of mineral veins.—The mineral veins with which we are most familiarly acquainted, are those of quartz and carbonate of lime, which are often observed to form lenticular masses of limited extent traversing both hypogene strata and fossiliferous rocks. Such veins appear to have once

been chinks or small cavities, caused, like cracks in clay, by the shrinking of the mass, during desiccation, or in passing from a higher to a lower temperature. Siliceous, calcareous, and occasionally metallic matters have sometimes found their way simultaneously into such empty spaces, by infiltration from the surrounding rocks. Mixed with hot water and steam, metallic ores may have permeated the mass until they reached those receptacles formed by shrinkage, and thus gave rise to that irregular assemblage of veins, called by the Germans a 'Stockwerk,' in allusion to the different floors on which the mining operations are in such cases carried on.

Mr. J. A. Phillips has proved that in Nevada hot springs rise to the surface and deposit silica, with metallic ores, which incrusts the walls of the fissures.

The more ordinary or regular veins, usually highly inclined or vertical, have evidently been fissures produced by mechanical violence. They traverse all kinds of rocks, both hypogene and fossiliferous, and extend downwards to indefinite or unknown depths. We may assume that they correspond with such rents as we see caused from time to time by the shock of an earthquake. Metalliferous veins are occasionally a few inches wide, but more commonly 3 or 4 feet, and some are 150 feet wide. They hold their course continuously in a certain prevailing direction for a short distance or for miles or leagues, passing through rocks varying in mineral composition.

Metalliferous veins were fissures.—There are proofs in almost every mining district of a succession of faults, by which the opposite walls of rents, now the receptacles of metallic substances, have suffered displacement. Thus, for example, suppose *a a*, fig. 626, p. 545, to be a tin lode in Cornwall, the term *lode* being applied to veins containing metallic ores. This lode, running east and west, is a yard wide, and is shifted by a copper lode (*b b*), of similar width. The first fissure (*a a*) has been filled with various materials, partly of chemical origin, such as quartz, fluor-spar, tinstone, copper-glance, arsenical pyrites, native bismuth, and nickeliferous pyrites, and partly of mechanical origin, comprising clay and angular fragments or detritus of the intersected rocks. The successive deposits of spars and ores are, in some places, parallel to the vertical sides or walls of the vein, being divided from each other by alternating layers of clay, or other earthy matter. Occasionally, however, the metallic ores are disseminated in detached masses among the sparry minerals or vein-stones.

It is clear that, after the gradual introduction of the tinstone and other substances, the second rent (*b b*) was produced by

another fracture accompanied by a displacement of the rocks along the plane of *b b*. This new opening was then filled with minerals, some of them resembling those in *a a*, as fluor-spar

Fig. 626.

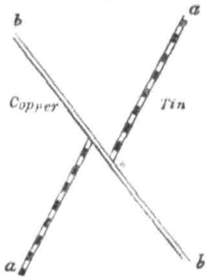


Fig. 627.

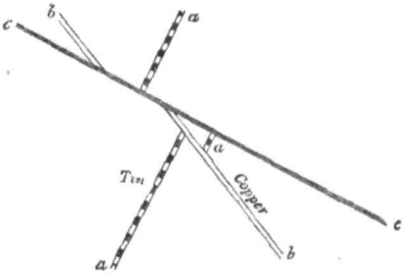
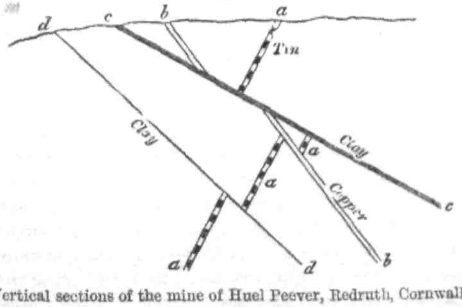


Fig. 628.



Vertical sections of the mine of Huel Peever, Redruth, Cornwall.

and quartz; others different, the copper ore being plentiful, and the tin ore wanting or very scarce. We must next suppose a third movement to occur, breaking asunder all the rocks along

the line *c c*, fig. 627 ; the fissure, in this instance, being only 6 inches wide, and simply filled with clay, derived, probably, from the friction of the walls of the rent, or partly, perhaps, washed in from above. This new movement has displaced the rock in such a manner as to interrupt the continuity of the copper vein (*b b*), and, at the same time, to shift or heave laterally in the same direction a portion of the tin vein which had not previously been broken.

Again, in fig. 628, we see evidence of a fourth fissure (*d d*), also filled with clay, which has cut through the tin vein (*a a*), and has lifted it slightly upwards towards the south. The various changes here represented are not ideal, but are exhibited in a section obtained in working an old Cornish mine, long since abandoned, in the parish of Redruth, called Huel Peever, and described both by Mr. Williams and Mr. Carne.[1] The principal movement here referred to, or that of *c c*, fig. 628, extends through a space of no less than 84 feet ; but in this, as in the case of the other three, it will be seen that the outline of the country above, *d*, *c*, *b*, *a*, &c., or the geographical features of Cornwall, are not affected by any of the dislocations, a powerful denuding force having clearly been exerted subsequently to all the faults. It is commonly said in Cornwall, that there are eight distinct systems of veins, which can in like manner be referred to as many successive movements or fractures ; and the German miners of the Hartz Mountains speak also of eight systems of veins, referable to as many periods.

Besides the proofs of mechanical action already explained, the opposite walls of veins are often beautifully polished, as if glazed, and are not unfrequently striated or scored with parallel furrows and ridges (slicken-sides), such as would be produced by the continued rubbing together of surfaces of unequal hardness.

In some of the veins in the mountain limestone of Derbyshire, containing lead, the vein-stuff, which is nearly compact, is occasionally traversed by what may be called a vertical crack passing down the middle of the vein. The two faces in contact are slicken-sides, well polished and fluted, and sometimes covered by a thin coating of lead-ore. When one side of the vein-stuff is removed, the other side cracks, especially if small holes be made in it, and fragments fly off with loud explosions, and continue to do so for some days. The miner, availing himself of this circumstance, makes with his pick small holes

1 Trans. Geol. Soc. vol. iv. p. 139 ; Trans. Royal Geol. Soc. Cornwall, vol. ii. p. 90.

about 6 inches apart and 4 inches deep, and on his return in a few hours finds every part ready broken to his hand.[2]

That a great many veins communicated originally with the surface of the country above, or with the bed of the sea, is proved by the occurrence of well-rounded pebbles in them, agreeing with those in superficial alluviums, as in Auvergne and Saxony. Marine fossil shells, also, have been found at great depths, having probably been engulphed during submarine earthquakes. Thus, the late Mr. Charles Moore described lead-veins traversing the Carboniferous limestone of the Mendips in Somerset, which at the time they were filled must have been in communication with the Liassic sea, for he found Lias fossils in them.[3] In Cornwall, Mr. Carne mentions true pebbles of quartz and slate in a tin lode of the Relistran Mine, at the depth of 600 feet below the surface. They were cemented by tinstone and copper pyrites, and were traced over a space more than 12 feet long and as many wide.[4] When different sets or systems of veins occur in the same country, those which are supposed to be of contemporaneous origin, and which are filled with the same kind of metals, often maintain a general parallelism of direction. Thus, for example, both the tin and copper veins in Cornwall run nearly east and west, while the lead-veins run north and south; but there is no general law of direction common to different mining districts. The parallelism of the veins is another reason for regarding them as ordinary fissures, for we observe that faults and trap dikes, admitted by all to be masses of melted matter which have filled rents, are often parallel.

Fracture, reopening, and successive formation of veins.—Assuming, then, that veins are simply fissures in which chemical and mechanical deposits have accumulated, we may next consider the proofs of their having been filled gradually and often during successive enlargements.

Werner observed, in a vein near Gersdorff, in Saxony, no less than thirteen beds of different minerals, arranged with the utmost regularity on each side of the central layer. This layer was formed of two plates of calcareous spar, which had evidently lined the opposite walls of a vertical cavity. The thirteen beds followed each other in corresponding order, consisting of fluor-spar, heavy spar, galena, &c. In these cases the central mass has been last formed, and the two plates which coat the walls of the rent on each side are the oldest of all. If they consist of crystalline precipitates, they may be explained by supposing

[2] Conyb. and Phil. Geol. p. 401; and Farey's Derbyshire, p. 243.

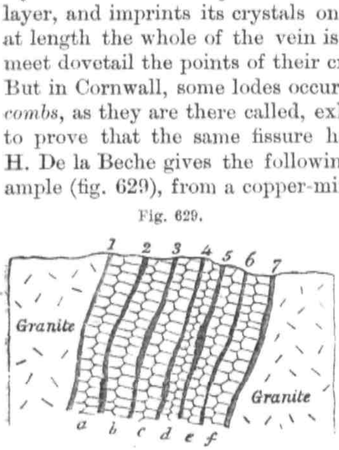
[3] Quart. Journ. Geol. Soc. vol. xxiii. (1867), p. 449.

[4] Carne, Trans. of Geol. Soc Cornwall, vol. iii. p. 238.

the fissure to have remained unaltered in its dimensions, while a series of changes occurred in the nature of the solutions which rose up from below ; but such a mode of deposition, in the case of many successive and parallel layers, appears to be exceptional.

If a veinstone consists of crystalline matter, the points of the crystals are always turned inwards, or towards the centre of the vein ; in other words, they point in the direction where there was space for the development of the crystals. Thus each new layer receives the impression of the crystals of the preceding layer, and imprints its crystals on the one which follows, until at length the whole of the vein is filled ; the two layers which meet dovetail the points of their crystals the one into the other. But in Cornwall, some lodes occur where the vertical plates, or *combs*, as they are there called, exhibit crystals so dovetailed as to prove that the same fissure has been often enlarged. Sir H. De la Beche gives the following curious and instructive example (fig. 629), from a copper-mine in granite, near Redruth.[5]

Fig. 629.



Copper lode, near Redruth, enlarged at six successive periods.

Each of the plates or combs (*a*, *b*, *c*, *d*, *e*, *f*) is double, having the points of their crystals turned inwards along the axis of the comb. The sides or walls (2, 3, 4, 5, and 6) are parted by a thin covering of ochreous clay, so that each comb is readily separable from another by a moderate blow of the hammer. The breadth of each represents the whole width of the fissure at six successive periods, and the outer walls of the vein, where the first narrow rent was formed, consisted of the granitic surfaces 1 and 7.

A somewhat analogous interpretation is applicable to many other cases, where clay, sand, or angular detritus alternate with ores and veinstones. Thus, we may imagine the sides of a fissure to be incrusted with siliceous matter after the manner observed by Von Buch, in Lancerote. He noticed that the walls of a volcanic crater formed in 1731 were traversed by an open rent in which hot vapours had deposited hydrous silica, the incrustation nearly extending to the middle.[6] Such a vein may subsequently be filled with clay or sand, and afterwards reopened, the new rent dividing the argillaceous deposit, and

[5] Geol. Rep. on Cornwall, p. 340.
[6] Principles, *Index*, 'Lancerote.'

allowing a quantity of rubbish to fall down. Various ores and spars may then be precipitated from aqueous solutions percolating among the interstices of this heterogeneous mass.

That such changes have repeatedly occurred, is demonstrated by the occurrence of occasional cross-veins, implying the oblique fracture of previously formed chemical and mechanical deposits. Thus, for example, M. Fournet, in his description of some mines in Auvergne worked under his superintendence, observes that the granite of that country was first penetrated by veins of massive granite and then dislocated, so that open rents crossed both the granite and the granitic veins. Into such openings, quartz, accompanied by iron pyrites and arsenical pyrites, was introduced. Another convulsion then burst open the rocks along the old line of fracture, and the first set of deposits was cracked and often shattered, so that the new rent was filled, not only with angular fragments of the adjoining rocks, but with pieces of the older veinstones. Polished and striated surfaces on the sides or in the contents of the vein also attest the reality of these movements. A new period of repose then ensued, during which various sulphides were introduced, together with quartz of the variety known as horn-stone, by which angular fragments of the older quartz before mentioned were cemented into a breccia. This period was followed by other dilatations of the same veins, and the introduction of other sets of mineral deposits, as well as of pebbles of the basaltic lavas of Auvergne, derived from superficial alluviums, probably of Miocene or even older Pliocene date. Such repeated enlargement and reopening of veins might have been anticipated, if we adopt the theory of fissures, and reflect how few of them have ever been sealed up entirely; and that a country with fissures only partially filled must naturally offer much feebler resistance along the old lines of fracture than anywhere else.

Cause of alternate contraction and swelling of veins.— A large proportion of metalliferous veins have their opposite walls nearly parallel, and sometimes over a wide extent of country. But many lodes in Cornwall and elsewhere are extremely variable in size, being 1 or 2 inches in one part, and then 8 or 10 feet in another, at the distance of a few fathoms, and then again narrowing as before. Such alternate swelling and contraction is so often characteristic as to require explanation. The walls of fissures in general, observes Sir H. De la Beche, are rarely perfect planes throughout their entire course, nor could we well expect them to be so, since they commonly pass through rocks of unequal hardness and different mineral composition. If, therefore, the opposite sides of such irregular

fissures slide upon each other, that is to say, if there be a fault, as in the case of so many mineral veins, the parallelism of the opposite walls is at once entirely destroyed, as will be readily seen by studying the annexed diagrams.

Let *a*, *b*, fig. 632, be a line of fracture traversing a rock, and

Fig. 630.

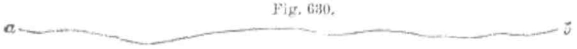
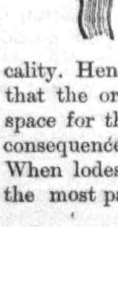


Fig. 631.

Fig. 632.

let *a b*, fig. 631, represent the same line. Now, if we cut in two a piece of paper representing this line, and then move the lower portion of this cut paper sideways from *a* to *a'*, taking care that the two pieces of paper still touch each other at the points 1, 2, 3, 4, 5, we obtain an irregular aperture at *c*, and isolated cavities *d d d*, and when we compare such figures with nature we find that, with certain modifications, they represent *the interior of faults and mineral veins. If we move* the lower part of the paper towards the left, about the same distance that it was previously slid to the right, we obtain considerable variation in the cavity so produced, two long irregular open spaces, *f f*, fig. 632, being then formed. This will serve to show to what slight circumstances, considerable variations in the character of the openings between unevenly fractured surfaces may be due, such surfaces being moved upon each other, so as to have numerous points of contact.

Fig. 633.



Most lodes are perpendicular to the horizon, or nearly so; but some of them have a considerable inclination or 'hade,' as it is termed, the angles of dip being very various. The course of a vein is frequently very straight; but, if tortuous, it is found to be choked up with clay, stones, and pebbles, at points where it departs most widely from verticality. Hence at places, such as *a*, fig. 633, the miner complains that the ores are 'nipped,' or greatly reduced in quantity, the space for their free deposition having been interfered with in consequence of the preoccupancy of the lode by earthy materials. When lodes are many fathoms wide, they are usually filled for the most part with earthy matter, and fragments of rock,

through which the ores are disseminated. The metallic substances frequently coat or encircle detached pieces of rock, which our miners call 'horses' or 'riders.' That we should find some mineral veins which split into branches is also natural, for we observe the same in regard to open fissures.

Chemical deposits in veins.—If we now turn from the mechanical to the chemical agencies which have been instrumental in the production of mineral veins, it may be remarked that those parts of fissures which were choked up with the ruins of fractured rocks must always have been filled with water; and almost every vein has probably been the channel by which hot springs, so common in countries of volcanoes and earthquakes, have made their way to the surface. For we know that the rents in which ores abound, extend downwards to vast depths, where the temperature of the interior of the earth is more elevated. We also know that mineral veins are most metalliferous near the contact of plutonic and stratified formations, especially where the former send veins into the latter, a circumstance which indicates an original proximity of veins at their inferior extremity to igneous and heated rocks. It is, moreover, acknowledged that even those mineral and thermal springs, which, in the present state of the globe, are far from volcanoes, are nevertheless observed to burst out along great lines of upheaval and dislocation of rocks.[7] It is also ascertained that, among the substances with which hot springs are impregnated, such as are volatile also occur in the gaseous emanations of volcanoes. The whole of these are also among the constituents of the minerals most usually found in veins, such as quartz, calc-spar, fluor-spar, the metallic sulphides, heavy-spar, brown-spar, and the oxides of iron. I may add that, if veins have been filled with gaseous emanations from masses of melted matter, slowly cooling in the subterranean regions, the contraction of such masses as they pass from a plastic to a solid state would, according to the experiments of Deville on granite (a rock which may be taken as a standard), produce a reduction in volume amounting to 10 per cent. The slow crystallisation, therefore, of such plutonic rocks supplies us with a force not only capable of rending open the incumbent rocks by causing a failure of support, but also of giving rise to faults whenever one portion of the earth's crust subsides slowly while another contiguous to it happens to rest on a different foundation, so as to remain unmoved.

Although we are led to infer, from the foregoing reasoning,

[7] See Dr. Daubeny's Volcanoes.

that there has often been an intimate connection between metalliferous veins and hot springs holding mineral matter in solution, yet we must not on that account expect that the contents of hot springs and mineral veins would be identical. On the contrary, M. E. de Beaumont has judiciously observed that we ought to find in veins those substances which, being least soluble, are not discharged by hot springs—or that class of simple and compound bodies which the thermal waters ascending from below would first precipitate on the walls of a fissure, as soon as their temperature began slightly to diminish. The higher they mount towards the surface, the more will they cool till they acquire the average temperature of springs, being in that case chiefly charged with the most soluble substances, such as the alkalies, soda and potash. These are seldom met with in veins, although they enter so largely into the composition of granitic rocks.[8]

To a certain extent, therefore, the arrangement and distribution of metallic matter in veins may be referred to ordinary chemical action, or to those variations in temperature which waters holding the ores in solution must undergo as they rise upwards from great depths in the earth. But there are other phenomena which do not admit of the same simple explanation. Thus, for example, in Derbyshire, veins containing ores of lead, zinc, and copper, but chiefly lead, traverse alternate beds of limestone and basalt. The ore is plentiful where the walls of the rent consist of limestone, but is reduced to a mere string when they are formed of basalt, or 'toad-stone,' as it is called provincially. Not that the original fissure is narrower where the basalt occurs, but because more of the space is there filled with veinstones, and the waters at such points have not parted so freely with their metallic contents.

Lodes in Cornwall are very much influenced in their metallic riches by the nature of the rock which they traverse, and they often change in this respect very suddenly, in passing from one rock to another. Thus many lodes which yield abundance of ore in granite, are unproductive in clay-slate, or killas, and *vice versâ*.

Supposed relative age of the different metals.—After duly reflecting on the facts above described, we must admit that it is very probable that mineral veins are referable to many distinct periods of the earth's history, although it may be more difficult to determine the precise age of veins; because they have often remained open for ages, and because, as we have

[8] Bulletin, Soc. Geol. France, iv. p. 1,278.

seen, the same fissure, after having been once filled, has frequently been reopened or enlarged. Sterry Hunt remarks that the process of filling veins has been going on from the earliest ages. We know of some which were formed before the Cambrian rocks were deposited, while others are still forming. It does not appear, however, that certain metals have been produced exclusively in earlier, others in more modern times—that tin, for example, is of higher antiquity than copper, copper than lead or silver, and all of them more ancient than gold.

In the first place, it is not true that veins in which tin abounds are the oldest lodes worked in Great Britain. The Government Survey of Ireland has demonstrated that in Wexford, veins of copper and lead (the latter as usual being argentiferous) are much older than the tin of Cornwall. In each of the two countries a very similar series of geological changes has occurred at two distinct epochs—in Wexford, before the Devonian strata were deposited; in Cornwall, after the Carboniferous epoch. To begin with the Irish mining district: we have granite in Wexford, traversed by granite veins, which veins also intrude themselves into the Silurian strata, the same Silurian rocks as well as the veins having been denuded before the Devonian beds were superimposed. Next we find, in the same county, that elvans, or straight dikes of porphyritic felsite, have cut through the granite and the veins before mentioned, but have not penetrated the Devonian rocks. Subsequently to these elvans, veins of copper and lead were produced, being of a date certainly posterior to the Silurian, and anterior to the Devonian; for they do not enter the latter, and, what is still more decisive, streaks or layers of derivative copper have been found near Wexford in the Devonian, not far from points where mines of copper are worked in the Silurian strata.

Although the precise age of such copper lodes cannot be defined, we may safely affirm that they were either filled at the close of the Silurian or commencement of the Devonian period. Besides copper, lead, and silver, there is some gold in these ancient or primary metalliferous veins. A few fragments also of tin found in Wicklow in the drift are supposed to have been derived from veins of the same age.[9]

Next, if we turn to Cornwall, we find there also the monuments of a very analogous sequence of events. First the granite was formed; then, about the same period, veins of fine-grained granite, often tortuous, penetrating both the outer crust of granite and the adjoining Palæozoic fossiliferous

[9] Sir H. De la Beche, MS. Notes on Irish Survey.

rocks, including the Coal-measures; thirdly, elvans, holding their course straight through granite, granitic veins, and fossiliferous slates; fourthly, veins of tin also containing copper, the first of those eight systems of fissures of different ages already alluded to, p. 546. Here, then, the tin lodes are newer than the elvans. It has indeed been stated by some Cornish miners that the elvans are in some instances posterior to the oldest tin-bearing lodes, but the observations of Sir H. De la Beche during the survey led him to an opposite conclusion, and he has shown how the cases referred to in corroboration can be otherwise interpreted.[1] We may, therefore, assert that the most ancient Cornish lodes are younger than the Coal-measures of that part of England, and it follows that they are of a much later date than the Irish copper and lead of Wexford and some adjoining counties. How much later, it is not so easy to declare, although probably they are not newer than the beginning of the Permian period, as no tin lodes have been discovered in any red sandstone which overlies the coal in the South-west of England.

There are lead veins in Glamorganshire which enter the Lias, and others near Frome, in Somersetshire, which have been traced into the Inferior Oolite. In Bohemia, the rich veins of silver of Joachimsthal cut through basalt containing olivine, which overlies tertiary lignite, in which are leaves of dicotyledonous trees. This silver, therefore, is decidedly a tertiary formation. In regard to the age of the gold of the Ural Mountains, in Russia, which, like that of California, is obtained chiefly from auriferous alluvium, it occurs in veins of quartz in the schistose and granitic rocks of that chain, and is supposed by Sir R. Murchison, MM. De Verneuil and Keyserling to be newer than the hornblendic granite of the Ural—perhaps of tertiary date. They observe, that no gold has yet been found in the Permian conglomerates which lie at the base of the Ural Mountains, although large quantities of iron and copper detritus are mixed with the pebbles of those Permian strata. Hence it seems that the Uralian quartz veins, containing gold and platinum, were not formed, or certainly not exposed to aqueous denudation, during the Permian era.

In the auriferous alluvium of Russia, California, and Australia, the bones of extinct land-quadrupeds have been met with, those of the mammoth being common in the gravel at the foot of the Ural Mountains; while in Australia they consist of huge marsupials (p. 128). The gold of Northern Chili is associated in the mines of Los Hornos with copper pyrites, in veins

[1] Report on Geology of Cornwall, p. 310.

traversing the Cretaceo-Jurassic formations, so called because its fossils are said to have the character partly of the cretaceous and partly of the jurassic fauna of Europe.[2] The gold found in the United States, in the mountainous parts of Virginia, North and South Carolina, and Georgia, occurs in metamorphic Silurian strata, as well as in auriferous gravel derived from the same. In Queensland, according to the researches of Mr. Daintree, the auriferous lodes are entirely confined to those districts which are traversed by a series of pyritous diorites.[3]

But Daintree discovered water-worn gold in a gravel containing *Glossopteris*, a fern of late Carboniferous age, in Queensland, and Wilkinson found evidence that some gold occurred in quartz of pre-Carboniferous age in Victoria. It may be said that the gold of Australia is found in diorite dikes, in Upper Silurian and Devonian rocks. Auriferous pyrites impregnate the dikes, especially near their points of contact with the other rocks, and quartz veins with gold intrude into the diorite. When the surface of the dike has been exposed to terrestrial or subaërial denudation, the gold has been preserved in the gravels and clays; but when marine denudation has happened, there is no gold to be found, or only in very small quantities. Basalts have overflowed the areas of denudation during the later tertiary times, and have preserved the gravels. Although gold-bearing quartz veins are found in New Zealand, of Cainozoic age, yet in Australia no gold-bearing dikes exist of Secondary or of Tertiary age. Their age is Palæozoic.

Gold has now been detected in almost every kind of rock, in slate, quartzite, sandstone, limestone, granite, and serpentine, both in veins and in the rocks themselves at short distances from the veins. In Australia it has been worked successfully not only in alluvium, but in veinstones in the native rock, generally consisting of Silurian shales and slates. It has been traced on that continent over more than nine degrees of latitude (between the parallels of 30° and 39° S.), and over twelve of longitude, and yielded in 1853 an annual supply equal, if not superior, to that of California.

Origin of gold in California and South America.—In 1864 Professor Whitney[4] showed that the detrital gold deposits worked in California were of fluviatile origin and of two distinct ages. The more ancient or Pliocene gravel deposit had been protected by a cover of hard lava poured out over it from the volcanoes of the higher part of the Sierra; whilst the later

[2] Darwin's S. America, p. 209, &c.

[3] Quart. Journ. Geol. Soc. vol. xxxiv. p. 431.

[4] Amer. Journ. Scien. Sept. 1864.

or Post-tertiary auriferous gravels, formed since the period of greatest volcanic activity above alluded to, contained remains of the mastodon and elephant, and belong to the epoch of man. He also announced that some of the gold veins themselves were probably of Cretaceous age, as had been shown to be the case in South America by Mr. David Forbes.[5] The last-mentioned mineralogist had already in 1861 advanced the opinion that the gold veins in South America and many other countries were of two distinct ages, and connected with the outbursts of Granitic and also of Dioritic rocks, the former or older being not later than the Carboniferous, and the latter as recent as the Cretaceous period.

Mr. J. Arthur Phillips stated his belief in 1868[6] that the formation of recent metalliferous veins is now going on in various parts of the Pacific Coast. Thus, for example, there are fissures at the foot of the eastern declivity of the Sierra Nevada in the State of that name, from which boiling water and steam escape, forming siliceous incrustations on the sides of the fissures. In one case where the fissure is partially filled up with silica enclosing iron and copper pyrites, gold is said to have been found in the veinstone.

It has been remarked by M. De Beaumont, that lead and some other metals are found in dikes of basalt as well as in mineral veins connected with trap-rock, whereas tin is met with in granite and in veins associated with the plutonic series. If this rule hold true generally, the geological position of tin accessible to the miner will belong, for the most part, to rocks older than those bearing lead. The tin veins will be of higher relative antiquity for the same reason that the 'underlying' igneous formations or granites which are visible to man are older, on the whole, than the overlying or trappean formations. Mr. David Forbes[7] has also found in South America and elsewhere, that not only are metallic lodes intimately associated with the appearance of eruptive rocks in their vicinity, but also that their metallic contents are strongly influenced by the nature of the rock so intruded.

Although heated waters may have had much to do with the production of metalliferous veins, still it must be remembered that water of ordinary temperature, assisted by the presence of organic matter, will decompose and render soluble many minerals which may be re-precipitated by subsequent oxidation.

If different sets of fissures, originating simultaneously at

[5] Quart. Journ. Geol. Soc. vol. xvii. 1861.

[6] Proc. Royal Soc. 1868, p. 294.

[7] Mineralogy of South America, Phil. Mag. vol. xxix.

different levels in the earth's crust, and communicating, some of them with volcanic, others with heated plutonic masses, be filled with different metals, it will follow that those formed farthest from the surface will usually require the longest time before they can be exposed superficially. In order to bring them into view, or within reach of the miner, a greater amount of upheaval and denudation must take place in proportion as they have lain deeper when first formed and fitted. A considerable series of geological revolutions must intervene before any part of the fissure, which has been for ages in the proximity of the plutonic rocks, so as to receive the gases discharged from it when it was cooling, can emerge into the atmosphere. But I need not enlarge on this subject, as the reader will remember what was said in the chapters on the chronology of the volcanic and hypogene formations.

Analysis of Minerals most abundant in the Volcanic and Hypogene Rocks.

	Silica	Alumina	Sesquioxide of Iron	Protoxides of Iron and Manganese	Lime	Magnesia	Potash	Soda	Other Constituents	Specific Gravity
THE QUARTZ GROUP.										
UARTZ	100·0	..	..	..	..	..	..	..	..	2·6
RIDYMITE	*100·0*	..	..	..	..	..	..	..	..	2·3
THE FELSPAR GROUP.										
RTHOCLASE. Carlsbad, in granite (Bulk).	65·23	18·26	0·27	..	trace	..	14·66	1·45	..	2·55
—— Sanidine, Drachenfels, in trachyte (Rammelsberg).	65·87	18·53	..	..	0·95	0·39	10·32	3·42	W. 0·44	
LBITE. Arendal, in granite (G. Rose)	68·46	19·30	..	0·28	0·68	..	..	11·27	..	2·61
LIGOCLASE. Ytterby, in granite (Berzelius).	61·55	23·80	..	..	3·18	0·80	0·38	9·67	..	2·65
—— Teneriffe, in trachyte (Deville)	61·55	22·03	..	..	2·81	0·47	3·44	7·74	..	2·59
ABRADORITE. Hitteroe, in Labrador-Rock (Waage).	51·39	29·42	2·90	..	9·44	0·37	1·10	5·63	W. 0·71	2·72
—— Iceland, in volcanic (Damour)	52·17	29·22	1·90	..	13·11	..	..	3·40	..	2·71
NORTHITE. Harzburg, in diorite (Streng).	*45·37*	*34·81*	*0·59*	..	*16·52*	*0·83*	*0·40*	*1·45*	W. 0·87	2·74
—— Hecla, in volcanic (Waltershausen)	45·14	32·10	2·03	0·78	18·32	..	0·22	1·06	..	
EUCITE. Vesuvius, 1811, in lava (Rammelsberg).	56·10	23·22	..	..	..	..	20·59	0·57	..	2·48
EPHELINE. Miask, in miascite (Scheerer).	44·30	33·25	0·82	..	0·32	0·07	5·82	16·02	..	2·59
—— Vesuvius, in volcanic (Arfvedson)	44·11	33·73	..	..	..	..	..	20·46	W. 0·62	2·60
THE MICA GROUP.										
USCOVITE. Finland, in granite (Rose).	46·36	36·80	4·53	..	..	..	9·22	..	F. 0·67 W. 1·84	2·90
EPIDOLITE. Cornwall, in granite (Regnault).	52·40	26·80	..	1·50	..	..	9·14	..	F. 4·18 Li. 4·85	2·90
IOTITE. Bodenmais (V. Kobell)	40·86	15·13	13·00	..	..	22·00	8·83	..	W. 0·44	2·70
—— Vesuvius, in volcanic (Chodnef)	40·91	17·71	11·02	..	0·30	19·04	9·96	..	..	2·75
HLOGOPITE. New York, in metam. limestone (Rammelsberg).	41·96	13·47	..	2·67	0·34	27·12	9·37	..	F. 2·93 W. 0·60	2·81
ARGARITE. Naxos (Smith)	30·02	49·52	1·65	..	10·82	0·48	1·25		W. 5·55	2·99
HLORITE. Dauphiny (*Marignac*)	26·88	17·[illegible]	29·76	..	..	13·84	..	..	W. *11·33*	2·87
IPIDOLITE. Pyrenees (Delesse)	32·10	18·50	..	0·06	..	36·70	..	..	W. 12·10	2·61
ALC. Zillerthal (Delesse)	63·00	..	..	trace	..	33·60	..	..	W. 3·40	2·68
THE AMPHIBOLE AND PYROXENE GROUP.										
REMOLITE. St. Gothard (Rammelsberg).	58·55	..	..	..	13·90	26·63	..	..	F.W. 0·34	2·93
TINOLITE. Arendal, in granite (Rammelsberg).	56·77	0·97	..	5·88	13·56	21·48	..	..	W. 2·20	3·02
ORNBLENDE. Faymont, in diorite (Deville).	41·99	11·66	..	22·22	9·55	12·59	..	1·02	W. 1·47	3·20
—— Etna, in volcanic (Waltershausen)	40·91	13·68	..	17·49	13·44	13·19	..	..	W. 0·85	3·21
RALITE. Ural (Rammelsberg)	50·75	5·65	..	17·27	11·59	12·28	..	..	W. 1·80	3·14
GITE. Bohemia, in dolerite (Rammelsberg).	51·1[illegible]	3·38	0·95	8·08	23·54	12·82	..	..	..	3·36
—— Vesuvius, in lava of 1858 (Rammelsberg).	49·61	4·42	..	9·08	22·82	14·22	..	..	..	3·25
ALLAGE. Harz, in Gabbro (Rammelsberg).	52·0[illegible]	3·10	..	9·36	16·29	18·51	..	..	W. 1·10	3·23
YPERSTHENE. Labrador, in Labrador-Rock (Damour).	51·36	0·37	..	22·59	3·09	21·31	..	..	..	3·39
ONZITE. Greenland (V. Kobell)	58·00	1·33	11·14	..	..	29·66	..	..	..	3·20
IVINE. Carlsbad, in basalt (Rammelsberg).	39·34	..	..	14·85	..	45·81	..	..	..	3·40
—— Mount Somma, in volcanic (Walmstedt).	*40·08*	*0·18*	..	15·74	..	*44·22*	..	..	..	3·33

In the last column but one of the above table the following signs are used: F. Fluorine; Li. Lithia; W. Loss on igniting the mineral, in most instances only water.

APPENDIX.

IN order to curtail this work, and also to afford information to the student, descriptions of the commonest rock-making minerals, and of the rocks usually met with, are placed in this Appendix. A few rocks have been noticed in the body of the book.

The Editor has gleaned from the works of Professors Bonney and Geikie, and from those of Messrs. Dana, Bauerman, and Rutley, and he acknowledges this very thankfully.

The foregoing table is principally due to the late David Forbes, F.R.S.

ROCK-MAKING MINERALS.

Silica is a dioxide of Silicon, and occurs in at least three different conditions,[1] each marked by distinct physical and crystallographical characters. Hexagonal tetartohedral in Quartz. Rhombic or asymmetric in Asmanite and Tridymite. Amorphous in Opal and Hyalite. Quartz, SiO_2; Silicon 46·67; Oxygen 53·33, is nearly infusible alone, insoluble, except in Hydrofluoric-acid, which decomposes it, slightly soluble in heated caustic alkaline liquors. Its sp. gr. is 2·65–2·66.

Tridymite completely soluble in a boiling solution of carbonate of soda, with sp. gr. 2·28–2·33, in minute six-sided crystals in some volcanic rocks. Asmanite is Meteoric.

Opal and Hyalite are amorphous Silicas, and have variable quantities of water.

Quartz, when in the form of crystals and perfectly colourless, is called Rock-crystal, or, popularly, Irish or Cornish Diamond. When coloured, it is called Amethyst (purple and dark blue); Cairngorm and Smoke Topaz when yellowish red and brown. Common Quartz includes the opaque or non-transparent kinds, and to it belong Rose and Milky Quartz, so called from their tints. Jasper is a compact quartz, yellow, brown, or red, or spotted, coloured with Limonite. Quartzite is a compact white or reddish, opaque quartz, and Lydian-stone is a black shining variety. Hornstone or Chert is compact, slightly translucent or opaque, with a horny lustre, and tints from grey, green, to brown.

[1] Bauerman, Descriptive Mineralogy, p. 132. 1884.

Cat's-eye is a greenish or blue grey or brown quartz, filled with parallel layers of Asbestus. Aventurine has mica. Some forms of Silica are amorphous, such as the Opals; and there are mixtures of both forms. Thus, Chalcedony, Flint, and Agate are mixtures of quartz and amorphous silica. *Silica is the most abundant of all minerals.*

Anhydrous Bisilicates.—Augite-Hornblende group.—Mr. Bauerman remarks that the normal silicates of lime, magnesia and manganese, whether containing only one base, or isomorphous mixtures of several, may be conveniently included under this head. They form several species, crystallising in the rhombic, oblique, and triclinic systems.

Pyroxene or Augite is a common mineral with several varieties, such as Augite, Malacolite, Sahlite, Fossoite, but the first is of the greatest importance. It occurs in short and long crystals. The *crystallographic system is the oblique, and the cleavage is in two* planes parallel with the sides of the prism, nearly at right angles to one another. The angle formed by the oblique rhombic prism is 87° 06′. The density is 2·9 to 3·5. Hardness 5–6, and the colour black and greenish (in common Augite of eruptive rocks). In chemical composition it is a silicate of lime, magnesia and manganese or iron, and therefore the common form is one of the Aluminous Pyroxenes. Other pyroxenes, such as Malacolite and Sahlite, have either a very small proportion of Alumina or none at all, the invariable composition being of silica, lime, magnesia, manganese, protoxide, and iron protoxide. The proportion of silica is from 47 to 55 per cent. in the aluminous varieties, and 49 to 56 per cent. in the non-aluminous. Under the blowpipe Augite is not easily fused. Thin sections of Augite, examined under the microscope, show feeble change of colour when the polariser is rotated without the analyser. It is found in basalts, and in many igneous rocks of all ages, but the light coloured and non-aluminous varieties are found in Gneisses and other crystalline and foliated rocks. The double refraction is positive. Augite is a common constituent of basalts and lavas.

Diallage is a thin *foliated variety*, with its *chemical* constitution, Silica 50·53 per cent., Magnesia 15·17, Lime 15·22, Alumina 1·4, Ferrous and manganous oxide 5·13 per cent. It has a fine fibrous structure, and a striated, mother-of-pearl looking surface. It is a constituent of Gabbro rock, and sometimes of Serpentines, and is very infusible.

Hornblende or Amphibole.—The minerals of this group closely resemble Augite in their chemical composition, and crystallise in the same (oblique) system. The angular measurement of the oblique rhombic prism is, however, 124° 30′. Thus there is a distinction from Augite; and this is also maintained in the angles at which the cleavage planes intersect. The colours of the two groups are very much the same, common Hornblende being dark brown, black, and greenish black. This mineral occurs in short crystals or as long acicular and prismatic forms.

Microscopical sections give decided change of tint when the polariser is rotated without the use of the analyser. The double refraction is negative. Density 2·9–3·5. Hardness 5–6. It is composed of Silica 48·8, Alumina 7·5, Magnesia 13·6, Lime 10·2, Iron

protoxide 18·8, Manganese protoxide 1·1 = 100. Hornblende fuses. It is closely allied to Augite, but is rarely found with it. Probably Hornblende is the result of very slow, and Augite of more rapid cooling. Hornblende is found in acidic rocks rather than in the basic, where Augite prevails. It occurs in syenite, diorite, and granite, and in a massive form in Hornblende rock and Hornblende schist. Other varieties, which are non aluminous, usually light in colour, and fibrous, are Actinolite, Tremolite, and Asbestus. They are found amongst metamorphic rocks.

Enstatite usually has a columnar structure, with a fibrous appearance on the cleavage surfaces; or it may be massive or granular, or lamellar. It may be colourless, or grey, yellow, green, or brown. The streak is white, and the lustre is vitreous, pearly on cleavage surfaces. H. 5·5, sp. gr. 3·10–3·30. It consists of silica 60 per cent., and magnesia 40 per cent. It is infusible. Enstatite is found in the Olivine bombs of the Eifel volcanoes, in the Serpentines of Cornwall and Lherz in the Pyrenees.

Bronzite is found under similar conditions as Enstatite, and, like it, occurs also in meteorites. It has some of the Magnesia replaced by oxide of Iron.

Hypersthene is usually found in foliated masses,and has a pearly or semi-metallic lustre, often with an iridescent appearance. The colour is dark green, black, to nearly copper-red ; it is translucent, opaque and brittle. The crystallisation is Rhombic, the density is 3·15–3·39. It is composed of silicate of magnesia and oxide of iron. With Labradorite felspar it forms Hypersthenite and Norite.

Leucite has a crystalline form nearly that of a trapezohedron, and is dimetric. It has an imperfect cleavage, and the crystals are often large, dull, glassy, and grey-white or small and disseminate. Composition, Silica 55·0, Alumina 23·6, Potash 21·5 = 100. It is found in volcanic rocks, and especially in Vesuvian lavas and some late basalts.

Unisilicates.—Olivine or Peridote is usually found as dispersed crystals or embedded grains of an olive-green colour, also yellowish green, transparent when lately fractured, and opaque when weathered. The crystals are Rhombic. Composition, Silica 41·39, Magnesia 50·90, Iron protoxide 7·71 = 100. It gives bright red and green colours under the polarising apparatus, and is frequently cracked and fissured, and Serpentine is developed within. It is very infusible. Olivine rocks are called Peridotites. Olivine is a component of Basalt and Gabbro ; by metamorphism the Peridotites become Serpentines.

THE FELSPAR GROUP.

Orthoclase, or common or potash felspar, is usually found in thick, often rectangular, prisms ; or it may be massive, granular, or coarsely lamellar. The crystals belong to the Monoclinic system, the cleavage planes are at right angles, and hence the name *Orthos*, straight ; *klasis*, cleavage. The colours are light, white, grey, and flesh-red being common. It is composed of Silica 64·7, Alumina 18·4, Potash 16·9 = 100. Soda sometimes replaces a portion of the potash. The mineral fuses with difficulty, and is not acted on by acids. Moderately strong colours are exhibited under the polarising apparatus, and when the crystals are twinned on the Carlsbad type, the colours differ on either side of a median line. In

massive specimens the mineral appears like a network of lines of varying thickness and colour which run at right angles to one another. Orthoclase occurs in granite, syenite, porphyry, trachyte, felsite, gneiss.

Sanidine, or glassy felspar, is a variety of Orthoclase, and, as its name implies, is fairly transparent. It occurs in large flat tables or in fine clear crystals or crystalline granules. Sanidine occurs in trachytes and in lavas.

Microcline *is a potash felspar closely allied to Orthoclase*, but is slightly triclinic, the angle between its cleavage planes varying but 16° from 90°. Colours: blue, opalescent, bright green, white, and flesh-red. It occurs in Syenite with Zircon.

All the other felspars are plagioclase, or have a slanting cleavage, and belong to the triclinic system.

Albite, soda felspar. The cleavage planes intersect at angles of 86° 24′ and 63° 36′, and the cleavage faces usually have a pearly lustre. The crystals are usually thick and tabular Composition: Silica 68·6, Alumina 19·6, Soda 11·8 = 100 It fuses, giving a yellow tint to the flame, and is not acted upon by acids. Usually Albite is found in granite veins, granites, and some volcanic rocks.

Oligoclase, or soda-lime felspar, occurs in cleavable masses which *have a greasy or glassy lustre. The colour is usually white*, grey-white, greyish-green, red, and the mineral is more or less transparent or subtranslucent. It is triclinic and is plagioclase in cleavage, the angle between the cleavage planes being 93° 50′ and 86° 10′. Composition: Silica 61·9, Alumina 24·1, Lime 5·2, Soda 8·8 = 100. It fuses, and is not acted on by acids. It occurs in granite, syenite, diorite, and in metamorphic rocks which contain much silica, and is often associated with Orthoclase.

Andesine, or Andesite, is a triclinic felspar, and is plagioclastic; the lime and soda are in equal proportions. Composition: Silica 63·82, Alumina 24·05, Soda 5·04, Lime 5·04, Potash 0·88 = 98·84. It has a vitreous lustre and is found with Augite in basaltic rocks and in some Syenites.

Labradorite, or lime-soda felspar, is a triclinic felspar, and is usually found in cleavable massive forms. It is a plagioclastic, and the angle between the cleavage planes is 93° 20′ and 86° 40′. The colour is dark grey, brown or greenish-brown, and there is a brilliant iridescence of blue-green, red, and yellow tints from the surfaces. Composition: Silica 52·9, Alumina 30·3, Lime 12·3, Soda 4·5 = 100. It fuses readily; is a component of many volcanic rocks, lavas, and especially of Basalts and Dolerites.

Anorthite, or lime felspar, is triclinic and plagioclase. The crystals are tabular, and it is found in the massive, granular, or coarsely lamellar form. The colour is white, grey, or reddish. Composition: Silica 43·1, Alumina 36·8, Lime 20·1 = 100. It fuses with difficulty, and occurs in basic eruptive rocks and lavas.

Nepheline is a basic felspar, with soda and a small amount of potash.

It will have been observed that these felspars may be classified by their chemical composition, by their crystalline system and nature of their cleavage, and also by the quantity of silica they contain. Those which have more than 60 per cent. of Silica may be called acidic, and those with less, basic felspars.

THE MICA GROUP.

* **The Micas** belong to the unisilicate series, and all the minerals of the group have the crystals monoclinic, the front plane angle of the base 120°, and cleave easily in very thin laminæ parallel to the base. The colours vary; the ordinary light-coloured mica is common mica or Muscovite, and the black is Biotite. Lepidolite is a light-coloured mica, and contains lithia; whilst Lepidomelane is black, and contains more iron than Biotite.

Muscovite, or common mica, or potash mica, is monoclinic and in oblique rhombic prisms; the crystals usually have the acute angle replaced, usually in plates or scales which are transparent, tough, and elastic. *The optic axial angle is 44° to 78°. Composition*: Silica 46·3, Alumina 36·8, Potash 9·2, Iron sesquioxide 4·5, Fluoric acid 0·7, Water 1·8 = 99·3. It is a constituent of granite, gneiss, and mica-schist.

Biotite, or magnesian mica, has the crystals usually in short erect rhombic hexagonal prisms, and is common in disseminated scales and aggregations. The colour is dark green to black, and it is transparent or opaque. The lustre is pearly on a cleavage surface, and the optic-axial angle less than 1°, and crystals often appear uniaxial. Composition: Silica 40·91, Alumina 17·79, Iron oxides 10, Magnesia 19·14, Potash 9·96.

Garnet is common in dodecahedrons and in trapezohedrons, and also massive granular, or lamellar. The crystals are often perfectly developed, and included in rocks, or the mineral may be in rounded grains. Garnets are found in granites, gneiss, and other schistose rocks, crystalline limestone, serpentine, granulite, and eclogite. H. 7–7·5; sp. gr. 31·6–4·38. Almost every variety of colour is found, the common tint being red, crimson to black. There are Alumina, Iron, and Chrome garnets.

CHLORITE GROUP.

Chlorite is a term applied to several minerals which may be regarded as varieties of one. The form is in green hexagonal tables, or in scaly, vermicular, or earthy aggregates. It is composed of Silica, Alumina, Magnesia, Ferrous oxide, and water.

Chlorite schist, as its name implies, contains the mineral, and it occurs as a product of the alteration of hornblende, in filaments, incrustations, and layers in many crystalline rocks.

Talc occurs usually in pearly foliated masses, separating easily into thin, translucent folia, often massive. It is trimetric and in right rhombic prisms. The feel is unctuous and the colour light green, or greyish white, or silvery white, or dark olive green. Composition: Silica 62·8, Magnesia 33·5, Water 3·7 = 100. It occurs massive, and is soapstone.

Serpentine is usually massive and compact, and of a dark olive-green or blackish-green colour, often streaked with other colours. It is sometimes yellowish or reddish. The massive pieces may be fibrous here and there, and the fracture is dull and semi-resinous. It is a hydrous magnesian silicate, and the composition is: Silica 43·48, Magnesia 43·48, Water 13·04, and a little ferrous silicate. The mineral is a product of the alteration of eruptive rocks containing Olivine or Enstatite, and also possibly of Glauconite.

SUBSILICATES.

The subsilicates contain some not very important rock-making minerals, and those to be noticed are—Tourmaline or schorl, found usually in prisms and needles with 3, 6, 9, or 12 sides terminated in a low three-sided pyramid, the sides being often rounded and striated. The colour is black, blue-black, and dark brown, and other tints may occur. The crystals (Rhombohedral) are brittle, more or less transparent, vitreous, inclining to resinous. The composition is very complicated. A type of the black kind has Silica 37·50, Boron trioxide 9·02, Alumina 30·87, Iron protoxide 8·54, Magnesia 8·60, Lime 1·33, Soda 1·60, Potash 0·73, Water 1·81 = 100. Some kinds contain Fluorine and others Lithia. The mineral is common in granite, gneiss, mica schist, &c.

Andalusite or Chiastolite (Rhombic) is usually found in elongated prisms, or in imperfectly developed crystals and aggregations. The colour is white, grey, reddish-brown, green, or violet. Lustre vitreous, transparent to opaque. It is a silicate of alumina, a portion of this last being replaced by ferric oxide and lime. The mineral is found in argillaceous schists, mica schists, gneiss, &c., and is a common product of the contact metamorphism of igneous masses. When the mineral is abundant, the rocks are called Chiastolite schists.

Titanite (sphene) occurs in oblique rhombic prisms with sharp edges like wedges, and greyish brown to black in colour. The lustre is resinous. Crystals transparent to opaque. Composition: Silica 30·6, Titanium dioxide 40·82, Lime 28·57 = 100.

Epidote occurs in elongated prisms, and is found granular, fibrous, and massive. It is yellowish-green in colour, and is translucent to opaque, with a vitreous lustre. Composition: Silica 37·83, Alumina 22·63, Lime 23·27, Iron sesquioxide 15·02, Iron protoxide 0·93, Water 2·05 = 100·73. It fuses to a black glass, which is usually magnetic. It occurs in crystalline rocks, especially in those containing hornblende.

It occurs in disseminated crystals in granite, syenite, and in dolerites and lavas, and near to the contact of intrusive rocks with sandstones. In Lake Superior copper district it is a constituent of the cupriferous rocks.

HYDROUS SILICATES.

Amongst the hydrous silicates are the *Zeolites*, or trap minerals, so called from being found in the cavities and fissures of amygdaloidal trap (p. 474). They are the result of alterations in the including rocks. They all yield water under heat in a closed tube. Lime—Harmatome or Phillipsite—contains silica, alumina, lime, and water, and has therefore considerable resemblance to felspar. Stilbite and Apophyllite are other forms.

Other hydrous silicates have a micaceous or thin foliated structure with the surface of the folia pearly.

PINITE GROUP.

Kaolin, a pure clay or hydrous silicate of alumina resulting from the decomposition of orthoclase and soda felspars. It occurs in large masses in the neighbourhood of St. Austell, Cornwall, and on the west side of Dartmoor, in Devonshire.

ORES OF IRON, TITANIUM, TIN, LEAD.

• **Iron.**—**Hæmatite,** or Red Iron Ore, is bright red or brown red in the mass, and bluish black in crystals. It is composed of Fe_2O_3, and is found in beds, veins, and also as a constituent of rocks. Crystals occur in volcanic districts. Fibrous or kidney hematite usually fills hollows in carboniferous limestone.

Ilmenite is Titaniferous Iron Ore with magnesia, and is common as a constituent of crystalline and igneous rocks. It is often found in 'iron sand' on beaches, and has then been derived from the waste of Labradorite or Norite. It is often mixed with magnetic iron ore.

Magnetic Iron Ore, black in colour, is strongly magnetic, and very abundant in the older crystalline rocks of the North of Europe. It is a combination of ferrous and ferric oxide.

Iron Pyrites, or Bisulphide of Iron, FeS_2, is found in rocks of all ages, and in mineral veins it commonly accompanies the sulphides of arsenic, copper, and silver, and gold is found with it also.

It replaces some structures in fossilization, and is found in cubic crystals or in a massive globular form, with a radiated structure.

Limonite, or Brown Iron Ore or Bog-iron Ore, is a very common ore, and is found in fibrous, granular, compact, and in concretionary forms; the colour is brown, including the various ochres and ambers, raw and burnt Sienna, and iron-rust. It is ferric oxide (85·6 per cent.) and water (14·4 per cent.). It usually contains silica and manganese, besides quartz, sand, clay, carbonate of lime, &c. The lake ore of Sweden is a Limonite, found in small pisolitic or money-like concretions, which are dredged up from the bottoms of lakes. Ochre, Umber, and Sienna earths are intimate mixtures of Limonite and clay.

Siderite, or Spathic Iron ore, is Ferrous carbonate with Ferrous oxide, 62; carbonic acid, 38 per cent. Usually contains Calcium, Magnesium, or Manganese in partial replacement of the Iron. Found in masses which are radiated, or finely granular. Infusible, and is turned to magnetic oxide. *Clay Iron ores* are in nodules of a dull bluish grey colour, becoming rusty brown by exposure. They are Carbonates of Iron with phosphoric acid and some Manganese.

Glauconite is dark olive-green in grains, with a dull lustre. It is a silicate of iron and potassium, water being present. It forms beds in many strata, and fills the cavities of marine testacea, and occurs as casts of them.

Rutile is Tetragonal, and the crystals are short and columnar, like those of Tinstone. The acicular and fibrous aggregates have the lustre metallic. Colour: Reddish-brown, hyacinth-red, violet, yellow, or nearly black. Rutile is an oxide of Titanium, TiO_2. It occurs in gneiss, granite and crystalline schists.

Cassiterite.—Tin-stone is found in short columnar or slender pyramidal crystals, the former being known as 'diamond-pointed,' and the latter as 'sparrable tin.' It also occurs in reniform and spheroidal masses of a radiating fibrous structure known as wood tin and toad's-eye tin, and massive, interspersed in grains, or as pebbles (stream tin). The lustre is adamantine, resinous, or horny. Sp. gr. 6·8–7; translucent, opaque; form, tetragonal. Colour: grey, some shade of yellow, brown, or black; streak, white.

It is Stannic dioxide, and usually contains some iron—1·5 to 2·5 per cent.—and occasionally silica and tantalic acid. Tinstone occurs in intimate association with quartz, mica, topaz, tourmaline, chlorite, iron, copper, and *arsenical pyrites*, &c. '*Stream tin*' is the detritus formed from the waste of 'tin-bearing' veins, and occurs in the gravels and alluvial deposits of rivers.

Graphite—plumbago, blacklead—consists of Carbon with variable amounts of ash, mostly iron, silica, and earthy matters. It is infusible and insoluble, and unaffected by acids. It is sectile and flexible in thin laminæ. Opaque, metallic in lustre, and the colour and streak iron grey, black. Graphite is found in granite, gneiss, and crystalline limestones, and in larger irregular masses, which are more or less lenticular in shape. It occurs in Diorite.

CALCIUM COMPOUNDS.

Calcite, or calc spar, is a compound of Carbon dioxide 44, Lime, 56 = 100, and is rhombohedral, with an easy cleavage. The crystals vary in form, and the fibrous and silky texture is not uncommon. It may be granular and compact. The purest crystals are transparent, with a vitreous lustre, and the massive kinds are usually opaque, and even earthy. The colours are white, light grey, reddish, or yellow. The massive varieties are of various shades, from white to black. The varieties are Iceland spar, galena spar, chalk, dog-tooth spar, &c. It enters into the composition of solid limestones, of like rocks, &c.

Aragonite.—Trimetric, in rhombic prisms, usually in confused crystals, having the form of hexagonal prisms. It occurs in globular and coralloidal shapes. The colour is white, grey, yellow, green, and violet. The lustre is vitreous. It has the same chemical composition as calcite. It occurs mostly in gypsum beds, and in connection with iron ores, also in basalts.

Dolomite is rhombohedral, the faces being sometimes curved; often granular, massive, and white, tinged with yellow, red, green, brown, and sometimes black. The lustre is more or less pearly. Composition: Calcium carbonate 54·35, Magnesium carbonate 45·65 = 100. Effervesces sparingly or not at all in cold dilute hydrochloric acid.

Gypsum, or hydrous calcium sulphate, is monoclinic, cleaving into thin pearly laminæ, with a vitreous surface; the plates bend in one direction, and are brittle in another. Composition: Sulphur trioxide 46·5, Lime 32·6, Water 20·9 = 100. Becomes white and exfoliates under the blowpipe. Varieties: Selenite, radiated and plumose gypsum, alabaster. It occurs in beds and crystals in limestones, clays, and volcanic rocks.

Anhydrite is anhydrous calcium sulphate.

Apatite, or calcium phosphate, is in hexagonal prisms, with imperfect cleavage. It may be massive, mammillary, fibrous. The lustre is vitreous to resinous, and the colour green, yellowish-green, yellow, brown. Worn crystals are nearly opaque.

Fluor spar has cubical or octahedral crystals, with purple, pale-green, dark-green, blue, or pink colours. They are transparent or translucent, and the lustre is vitreous. H. 4; sp. gr. 3·16–3·19. It is a fluoride of calcium, and is common as a vein

mineral, being found with tin, lead, silver, and copper ores. Also with quartz, and in granites and crystalline rocks.

Bauxite occurs in pisolitic granules or in compact masses, and is amorphous. The colour is white, grey, yellow, rusty brown, or red. It is a mixture of hydrates of alumina and ferric oxide. It occurs with the iron ore on the Antrim basalt (p. 491).

Crystalline Rocks.—In classifying the crystalline rocks, Bunsen divided them into acidic, with more than 60 per cent. of silica, and basic, with less than that amount. Thus, the trachytes would represent the former, and the basalts the latter division. In studying both of these groups of rocks, it will be observed that in some the crystals contained in them are visible to the naked eye, whilst in others they are more or less microscopic.

Granite may be taken as the example of a rock with visible crystals, and Felsite of one with crystals requiring amplification to be visible. Sometimes some crystals are exceedingly large, and then the rock is called a Porphyry. The crystalline rocks may therefore be Crystalline, Micro-crystalline, and Porphyritic. In all these rocks the crystals are in simple apposition.

Fig. 634.

Porphyry.
White crystals of felspar in a dark base of hornblende and felspar.

In some rocks termed Vitreous, the crystals are united by a more or less glassy matrix, which may be amorphous, or which can be resolved, under the microscope, into exceedingly small crystals. The amorphous substance is called 'basis,' and the minutely crystalline matter is 'ground-mass,' and it consists of excessively small crystals of Orthoclase felspar, which constitute 'felsitic matter.'

Other rocks which have large crystals visible to the naked eye, and isolated as it were by minute crystals or by 'basis,' are said to be porphyritic. When the 'ground-mass' is made up of recognisable minerals, it is termed micro-crystalline;' while those parts which are simply made up of crystals without any definite characters are called 'crypto-crystalline.' It is common to find in the vitreous rocks, which are natural glasses, minute crystallites and crystals; the former being imperfect developments of amorphous mineral matter towards the crystalline state, and the latter being imperfect at their angles and edges. Some of these Vitreous rocks have remarkable internal structures, the homogeneous condition being very rare. Some internal appearances are due to movements of the mass during cooling. Such are bands of different tints and of strings of granular matter or lenticular streaks; perlitic structure, in which spheroidal or elliptical figures are packed in between minute rectilinear fissures which traverse the rock in all directions; spherulitic structure, or a kind of concretionary formation resulting from incipient crystallisation around certain points or nuclei, such as a crystallite for instance. Streaming in definite curved and meandering paths, the microliths being

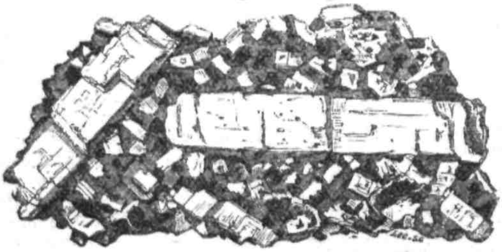
arranged with their long axes in the direction of streams and flows, fluxion structure is the name then given. All the Vitreous rocks and the glassy bases of the other rocks are liable to molecular changes termed 'devitrification;' these consist of the formation of minute granules and microliths, or of crystals which destroy the former glassy appearance, and give a dull look to the specimens. Mr. Rutley remarks that the last stage of this process is the formation of 'felsitic matter;' and when a rock has undergone complete change of this kind, it is only possible to arrive at conclusions as to its once vitreous nature, by means of those structural peculiarities which indicate former fluxion, &c.

All these differences of crystalline nature, general structure, and percentage of silica, are important in classifying rocks; but in that difficult proceeding the most ready plan is to consider the dominant mineral. A number of the most important rocks may be arranged according to the felspars in them, due attention being paid to the structural and chemical distinctions.

FELSPATHIC ROCKS.—ORTHOCLASE ROCKS WITH QUARTZ.

Granite.—This is a granular mixture of orthoclase and quartz, with mica. The felspar predominates as a rule, and the quartz is not in perfect crystals, but in irregular granules, having a vitreous lustre, or they may be of a pale grey colour. The quartz probably solidified later than the other constituents. The mica may be either potash or magnesian mica. In colour the felspar may be pink, brick-red, pale grey, and rarely greenish. It contains often, but not invariably, microscopic cavities more or less filled with liquid. Similar enclosures are much more common in the quartz. There is no 'basis'

Fig. 635.



Porphyritic Granite. Cornwall.

matter present, and the crystals are in simple apposition. There are many minerals adventitious to granite, such as grey or greenish triclinic felspar, talc, chlorite, tourmaline, apatite, fluorspar, hornblende, &c.

Porphyritic Granite has large crystals of felspar surrounded by much less defined small crystals of the other constituent minerals.

Granitite is almost made up of red orthoclase and oligoclase, with a small amount of quartz and black mica. **Granulite** is a fine-grained, vein granite. **Protogine** contains orthoclase, oligoclase,

quartz, green mica, and talc occurs as an alteration product. **Pegmatite** is an aggregate of large grains of orthoclase, white quartz, and large flakes of white silvery mica; tourmaline is also usually present. **Graphic Granite** is an aggregate of large crystals of felspar which are traversed by numerous crystals of quartz, distributed in parallel lines, so that when fracture occurs irregular shapes are produced, resembling, more or less, Hebraic letters.

Quartz-Trachyte or Quartz-Rhyolite, or Liparite.—The felspar is orthoclase, sanidine mainly, and some plagioclase may be present. In some instances the rock is porphyritic. The quartz occurs in definite crystals and in roundish grains. There is a general absence of fluid lacunæ in these quartzes, and this very different to what is seen in granites. This rock has a compact or finely granular substance, which is often porous and rough; it sometimes resembles hornstone or porcellanite, while at others it has a dull, earthy, or kaolinised appearance. It varies considerably in appearance and colour; brick-red, reddish-grey, and yellowish-white tints being common.

Felstone, Felsite, Eurite, Hälleflinta.—These are almost synonymous terms. According to Mr. Rutley, felstone is a more or less compact rock, those varieties called Hälleflinta and Hornstone having a peculiarly flinty aspect, while in other cases the rock is either finely crystalline-granular or granular, sometimes porphyritic. The Eurites proper are more readily fusible than the true felstones. In the compact and in the non-porphyritic varieties no definite minerals can be detected with the naked eye or with a lens, and the same may be said of the matrix in which porphyritic crystals occur. In colour, felstone varies very greatly; brick-red, brown, grey, yellowish and greyish-white tints being the most common. Many varieties have a more or less conchoidal fracture, and all are fusible on the edges of splinters to a white or speckled enamel. They differ in chemical composition, the amount of silica ranging from 70 to 80 per cent. Rutley gives the following mineralogical description of felstone:—It consists of felsitic matter, which is an intimate granular-crystalline, micro-crystalline, or crypto-crystalline admixture of Orthoclase and Quartz, in which crystalline granules of plagioclase felspars not unfrequently occur. In this felsitic base, which typically constitutes the matrix of all felstones, felspar crystals (Orthoclase) are often developed. Such rocks are *Felstone-Porphyries*. If in this matrix Quartz should occur, either porphyritically in crystals, or in rounded blebs, the rock is called *Quartz-Porphyry*, or *Quartz-Felsite*. It seems probable that the matrix of true Quartz-Porphyries should, in many cases, be regarded as a very fine-grained granite. Rocks of this class are called Elvans by the Cornish miners.

The other rocks of this group are glassy.

Pitchstone is a glassy rock with a splintery or conchoidal fracture and a pitch-like lustre. Specimens are blackish-green, dark olive-green, or brown in colour. Chemically they are like Obsidian, and contain from 63 to 73 per cent. of silica. The crystals they may present to the microscope are Sanidine, Hornblende, and Magnetite. Credner notices in the pitchstones of Meissen, microscopic crystals and quartz, sanidine, plagioclase, and mica; he places the rock in this quartziferous group.

Rocks with Orthoclase predominating, are with free quartz as a rule.

Syenite, in the typical form, is composed of orthoclase and hornblende; mica and quartz are not present. But as there are no hard and fast lines in nature, the typical form is found associated with other minerals which complicate it exceedingly. Quartz may be present, forming Quartz-Syenite, and when mica exists in combination, the rock is a Syenitic Granite. Augite may also occur. Plagioclase felspars sometimes occur in Syenite, and Mica Syenite is not an uncommon rock. Credner even defines Syenite as an aggregate of orthoclase, oligoclase, quartz, and a little mica.

Trachyte, a highly silicated rock, is normally composed of sanidine, oligoclase, hornblende, sometimes augite, magnesian mica, magnetite, &c. The name is derived from Τραχὺς (rough), in allusion to the rough, scraping sensation which the surfaces of these rocks usually convey to the hand. The more highly silicated trachytes are comprised in the group of Rhyolites, and may be studied under three heads. *Trachyte proper*, or quartzless trachyte, has no free quartz visible. The colour is greyish or yellowish to reddish-brown, and the matrix consists of colourless felspar microliths, which, by their arrangement in certain directions, frequently indicate fluxion. Spiculæ and granules of hornblende and specks of magnetite are also mixed up with the felspar microliths. Large porphyritic crystals of sanidine, and sometimes plagioclase felspars, are seen occasionally, and hornblende is common. Tridymite sometimes occurs. *Domite* is an altered trachyte with at least 68 per cent. of silica, probably due to Tridymite. It is from the Puy-de-Dôme, in Auvergne.

Sanidine trachyte consists of minute crystals of Sanidine felspar interspersed with glassy matter. Hornblende and magnetite are present; but this matrix contains no visible quartz, although the rock has over 72 per cent. of silica.

Orthoclase-Porphyry stands to the Syenites in the same relation that quartz-porphyry does to the Granites. It is composed of a compact porphyritic ground-mass, with little or no free quartz, but with crystals of orthoclase, hornblende, biotite, and also a little triclinic felspar. The rock is sometimes called Syenite-Porphyry, and it is associated with Syenite as some Elvan is with Granite.

Minette is one of the Mica traps. Magnesian mica is an important constituent, and there is some free quartz, and some hornblende, or augite. The crystalline forms may be termed Minette, and it occurs in dikes. Probably other forms are kinds of felstones.

Phonolite or Clinkstone is a name applied to compact grey or brown rocks which yield a ringing sound when struck; they consist of a quartzless mixture of sanidine and nepheline. Nosean and hornblende occur. The percentage of silica is only 57·7 per cent. It is found splitting into flags, and it readily decomposes.

The glassy rocks of this series are *Trachytic pitchstone* and *Obsidian*. This last is a vitreous rock with homogeneous appearance and dark glassy lustre; the fracture is eminently conchoidal, and in thin splinters; the rock is more or less transparent. No crystalline structure is developed. It is a true natural glass; but microliths are frequently seen, and, when spherulitic, the spherulites commonly show a radial crystalline or fibrous structure. Obsidians vary in

chemical composition: the silica may be from 63 to 80 per cent., the alumina 18 to 19 per cent., and the other constituents are soda or potash, lime, magnesia, peroxide of iron, and occasionally as much as 0·5 of water. The density is between 2·4 and 2·5, and the hardness is 6 to 7. Obsidians are common where there are Trachytes, and are also found as lava flows. They are true volcanic glasses.

Perlite is rather a petrological condition than a rock itself, is sometimes glassy in appearance, but it usually exhibits a pearly, enamel-like, or greasy aspect on recently fractured surfaces. The colour is mostly pale grey, blue grey, or yellow brown. It often appears to be composed of grains of a round or spherical shape, which have a somewhat concentric structure; but the rock is often homogeneous.

The next group of rocks has triclinic felspars predominating, besides—Hornblende, Augite, Diallage, Hypersthene, Mica, and Olivine.

ROCKS WITH TRICLINIC FELSPARS AND HORNBLENDE.

Diorite.—The term Greenstone is now restricted to the mineral Diorite, which is a crystalline-granular mixture of Triclinic felspar and hornblende. The felspar is sometimes Oligoclase, sometimes Labradorite.

Oligoclase-diorite is a crystalline granular admixture of oligoclase and hornblende. The texture of the rock varies from fine to cross grained, and the colour is variable, being sometimes greenish grey, at others greenish black, while some of the coarser grained varieties have a speckled or bleached appearance. The rocks are sometimes very compact in texture, and then are called *Diorite-aphanites*. The oligoclase is usually white or greenish white. The hornblende is mostly greenish black, sometimes brownish, and it occurs in long blade-like crystals or in imperfect crystals and grains. The majority of the Diorites are quartzless; but some contain Quartz, and are then termed *Quartz-diorites*.

Tonalite is another name for Quartz-diorite, and consists of quartz, oligoclase, and hornblende. Magnesian mica usually is present.

Diorite-Porphyrites are composed of a brown or dark grey base, compact in appearance, with segregations of white, reddish or greenish triclinic felspar, of hornblende, dark in tint; or mica may replace this last. It is thus Dioritic so far as its elements are concerned, and is porphyritic in structure. In some of these rocks crystals of oligoclase predominate, and they are then called Oligoclase-porphyrites. When hornblende crystals are large and in excess, the rock is termed Hornblende-porphyrite. The matrix of these rocks is either felsitic or micro-aphanitic.

Hornblende-Andesites.—These are divided into quartzose and quartzless kinds, and *Dacite* belongs to the first. It is a blackish, grey-green, brown, or deep green, compact, or finely granular rock, composed of oligoclase or andisine and sanidine, spiculæ of hornblende, mica, and quartz. The matrix itself is of microliths of plagioclase, sanidine and hornblende, and magnetite. The silica amounts to 66 per cent.

The quartzless hornblende-andesites contain tabular crystals of

oligoclase, white or greenish, and black crystals of hornblende. Sanidine is rare, and the silica only amounts to 60·75 per cent.

Propylite is an altered rock closely allied to the last noticed.* Zirkel states that it contains felspars filled with hornblende, while the larger hornblende crystals are entirely altered into vivid yellow Epidote, occurring in aggregates, or in small rounded grains. It may be quartziferous or the reverse.

ROCKS WITH TRICLINIC FELSPAR AND AUGITE.

Augite-Andesite is a combination of augite and either oligoclase or sanidine; hornblende may be present, and also magnetite. The silica in the Augite-Andesites is sometimes less than 60 per cent. They are eruptive rocks.

Diabase is a crystalline granular admixture of triclinic felspar and Augite, with usually more or less Magnetite and titaniferous iron. Some of the rocks thus called contain Quartz, and they are consequently divided into quartz-diabase and quartzless diabase, or diabase proper. The felspar present is either oligoclase or labradorite.

The Diabases contain other minerals, and chlorite occurs, but is a secondary product. *Viridite* is a green alteration product, and it is seen within the crystals of Augite and between the other crystals of the rock, and is allied to Chlorite. In quartzless Diabase the rock is crystalline in structure, and contains no trace of a glassy structure or of a devitrified base. The per cent. of Silica is 44·6.

In *Quartz-Diabase*, quartz and biotite are always present. It is coarse-grained in texture, and the quartz occurs in small granules, seldom larger than a pin's head. Olivine may occur: Silica 53·3 per cent. Some Diabase rocks are schistose, and contain a very large proportion of green Chloritic matter, frequently in scales. It is now taught that Diabase is produced by the alteration of Basalts and Dolerites, a Chloritic mineral being developed.

Melaphyre is an altered Dolerite. These rocks were of Palæozoic age, and were the basalts of their time. It is an unsatisfactory term.

Basalt, *Dolerite*, and *Anamesite* are names given to rocks without a mineralogical difference of any importance, but whose texture and crystalline appearance are not the same. They are lavas and intrusive rocks.

Basalt may be taken as the type. It is a dark-tinted rock, and the constituents are minute, and are triclinic felspar, augite, magnetite, ilmenite, and olivine. There may be a glassy basis.

Dolerite has the minerals visible to the naked eye, and there is no glassy amorphous basis. *Anamesite* has the texture so fine, that only a finely crystalline or granular structure is seen.

Tachylite is the vitreous representative of the Basalts.

ROCKS CONTAINING TRICLINIC FELSPAR AND DIALLAGE OR HYPERSTHENE.

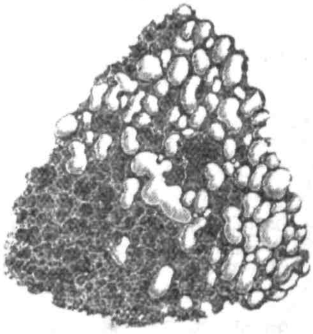
Gabbro is a crystalline, granular, dark-coloured aggregate of triclinic felspar, usually labradorite and diallage, without any basis. Olivine is sometimes present, or smaragdite may replace the diallage. *Gabbro occurs in the form of intrusive masses of considerable size, and in dikes, veins, and in sheets.*

Norites consist of plagioclase and hypersthene with some orthoclase and diallage.

Leucite Basalt and Nepheline Basalt consist of triclinic felspar and leucite and nepheline respectively.

Amygdaloid.—This is a form of igneous rock admitting of every variety of composition. It comprehends any rock in which round or almond-shaped nodules of some mineral such as agate, chalcedony, calcareous spar, or zeolite are scattered through a base of basalt, greenstone, or other kind of trap. It derives its name from the Greek word *amygdalon*, an almond. The origin of this structure cannot be doubted, for we may trace the process *of its formation in modern* lavas. Small pores or cells are caused by bubbles of steam and gas confined in the melted matter. After or during consolidation, these empty spaces are gradually filled up by matter separating from the mass, or infiltered by water permeating the rock. As these bubbles have been sometimes lengthened by the flow of the lava before it finally cooled, the contents of such cavities have *the form of almonds. In some* of the amygdaloidal traps of Scotland, where the nodules have decomposed, the empty cells are seen to have a glazed or vitreous coating, and in this respect exactly resemble scoriaceous lavas, or the slags of furnaces.

Fig. 636.



Scoriaceous lava in part converted into an amygdaloid.
Montagne de la Veille, Department of Puy-de-Dôme, France.

The annexed figure represents a fragment of stone taken from the upper part of a sheet of basaltic lava in Auvergne. *One half is* scoriaceous, the pores being perfectly empty; the other part is amygdaloidal, the pores or cells being mostly filled up with carbonate of lime, forming white kernels.

Lava.—This term has a somewhat vague signification, having been applied to all melted matter observed to flow in streams from volcanic vents. *When this matter consolidates in the open air,* the upper part is usually scoriaceous, and the mass becomes more and more stony as we descend, or in proportion as it has consolidated more slowly and under greater pressure. At the bottom, however, of a stream of lava, a small portion of scoriaceous rock very

frequently occurs, formed by the first thin sheet of liquid matter, which often precedes the main current, and solidifies under slight pressure.

The more compact lavas are often porphyritic, and the scoriaceous parts sometimes contain imperfect crystals, which have been derived from some older rocks, in which the crystals pre-existed, but were not melted, as being more infusible in their nature. Although melted matter rising in a crater, and even that which enters a rent on the side of a crater, is called lava, yet this term belongs more properly to that which has flowed either in the open air or on the bed of a lake or sea. There is every variety of composition in lavas; some are trachytic, as in the Peak of Teneriffe; a great number are basaltic, as in Auvergne; others are andesitic, or intermediate in composition between basalts and trachytes, as those of Chili; while many of the lavas of Etna consist of dolerites with Labrador-felspar.[1]

Scoriæ may be mentioned as porous rocks, produced by the escape of steam and gases from cooling lavas. *Scoriæ* are usually of a reddish-brown and black colour, and are the cinders and slags of lavas.

Pumice is a porous vesicular glass, which may be dull white or greenish yellow in colour. The vesicles are frequently elongated, sometimes in a more or less definite direction, while at others they anastomose, and give rise to an irregular network of fibrous intervesicular matter. The percentage of silica is from 57 to 73. Water is present, and the density is 1·9 to 2·5. It is fusible. Pumice occurs in the form of ejected blocks, and is produced, as scoriæ, on the cooling surfaces of Obsidian flows.

Volcanic ash or tuff, *Trap tuff.*—Small angular fragments of scoriæ and pumice, and the dust of the same, produced by volcanic explosions, form the tuffs which abound in all regions of active volcanoes, where showers of these materials, together with small pieces of other rocks ejected from the crater, and more or less burnt, fall down upon the land or into the sea. Here they often become mingled with shells, and are stratified. Such tuffs are sometimes bound together by a calcareous cement, and form a stone susceptible of a beautiful polish. But even when little or no lime is present, there is a great tendency in the materials of ordinary tuffs to cohere together. The term *Volcanic ash* has been much used for rocks of all ages supposed to have been derived from matter ejected in a melted state from volcanic orifices. Its crystals are minute and broken. We meet occasionally with extremely compact beds of volcanic materials, interstratified with fossiliferous rocks. These may sometimes be tuffs, although their density or compactness is such as to cause them to resemble many of those kinds of trap which are found in ordinary dikes.

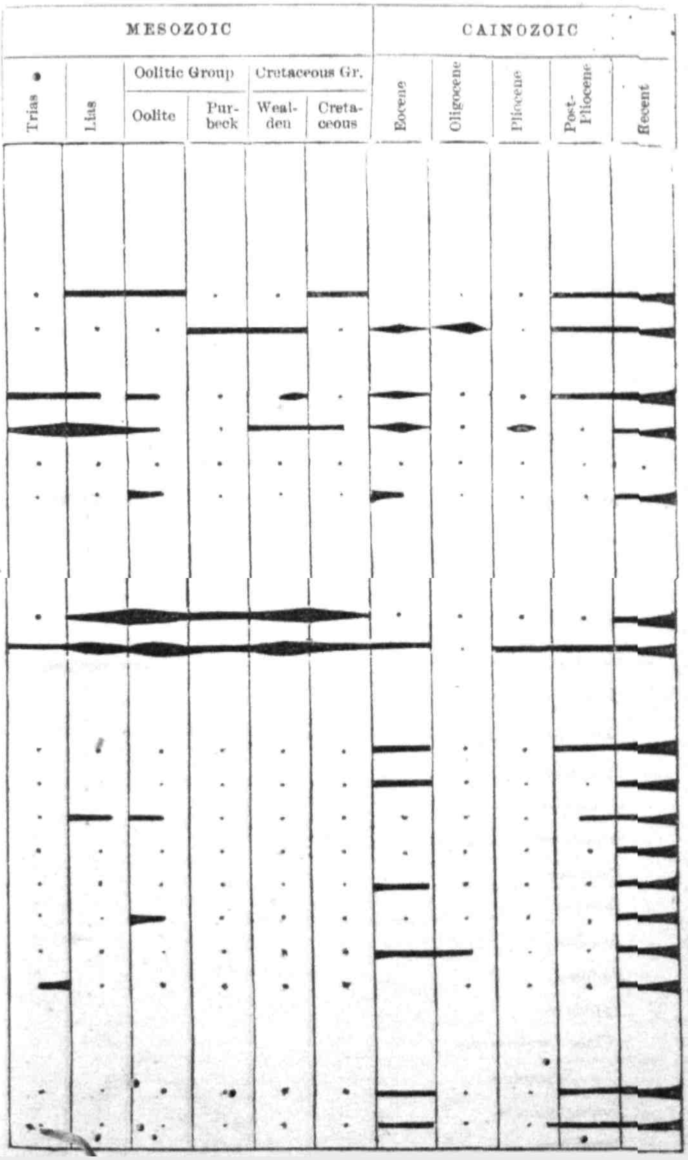
Wacke is a name given to a decomposed state of various trap rocks of the basaltic family, or those which are poor in silica. It resembles clay of a yellowish or brown colour, and passes gradually from the soft state to the hard dolerite, greenstone, or other trap rock from which it has been derived. *Claystone* is a similar material produced by the decomposition of andesitic or trachytic lavas.

[1] G. Rose, Ann. des Mines, tom. viii. p. 32.

Agglomerate.—In the neighbourhood of volcanic vents, we frequently observe accumulations of angular fragments of rocks formed during eruptions by the explosive action of steam, which shatters the subjacent stony formations, and hurls them up into the air. They then fall in showers around the cone or crater, or may be spread for some distance over the surrounding country. The fragments consist usually of different varieties of scoriaceous and compact lavas; but other kinds of rock, such as granite or even fossiliferous limestones, may be intermixed; in short, any substance through which the expansive gases have forced their way. The dispersion of such materials may be aided by the wind, as it varies in direction or intensity, and by the slope of the cone down which they roll, or by floods of rain, which often accompany eruptions. But if the power of running water, or of the waves and currents of the sea, be sufficient to carry the fragments to a distance, their angles can scarcely fail to be worn off, and the formation may become a *conglomerate*. If occasionally globular pieces of scoriæ abound in an agglomerate, they may not always owe their round form to attrition. Rocks formed by the consolidation of angular fragments of volcanic rocks are usually termed *volcanic breccias*.

Laterite is a red or brick-like rock composed of silicate of alumina and oxide of iron. The red layers, called 'ochre beds,' dividing the lavas of the Giant's Causeway and the Inner Hebrides, which are often called bole or lithomarge, appear to be analogous to the Indian laterites. These were found by Delesse to be trap impregnated with the red oxide of iron, and in part reduced to kaolin. When still more decomposed, they were found to be clay coloured by red ochre. As two of the lavas of the Giant's Causeway are parted by a bed of lignite, it is not improbable that the red layers seen in the Antrim cliffs resulted from atmospheric decomposition. The vegetable soil in the gardens of the suburbs of Catania, which was overflowed by the lava of 1669, was turned or burnt into a layer of red brick-coloured stone, similar to laterite, which may now be seen supporting the old lava-current. In Madeira and the Canary Islands streams of lava of subaërial origin, are often divided by red bands of laterite, probably ancient soils formed by the decomposition of the surfaces of lava-currents; many of these soils having been coloured red in the atmosphere by oxide of iron, others burnt into a red brick by the overflowing of heated lavas. These red bands are sometimes prismatic, the small prisms being at right angles to the sheets of lava. Red clay or red marl, formed as above stated by the disintegration of lava, scoriæ, or tuff, has often accumulated to a great thickness in the valleys of Madeira, being washed into them by alluvial action; and some of the thick beds of laterite in Hindostan may have had a similar origin. In the Peninsula of India the term 'laterite' has been used for a rock, which is gneiss altered *in situ*.

Classes, Orders, and Families	Palæozoic					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Kingdom **PLANTÆ.**						
Sub-Kingdom **Cryptogamia.**						
Cellulares.						
Fam. Algæ	.	—	—	—	—	—
— Characeæ	.	.	.	.	.	.
Thallogamia.						
Fam. Equisetaceæ	.	.	.	—	—	—
— Filices	.	.	.	—	—	—
Sporogamia.		.	.	.	.	.
Fam. Lycopodiaceæ	.	.	? —	. —	—	—
Sub-Kingdom **Phanerogamia.**						
Division *Gymnospermia.*						
Fam. Cycadaceæ	.	.	.	.	.	.
— Coniferæ	.	.	.	—	—	—
Division *Angiospermia.*						
Class *Monocotyledones.*						
Fam. Cyperaceæ	.	.	.	.	.	.
— Gramineæ	.	.	.	.	.	.
— Naiadaceæ	.	.	.	.	.	.
— Pandanaceæ	.	.	.	.	.	.
— Nipaceæ	.	.	.	.	.	.
— Aroideæ	.	.	.	.	—	.
— Palmæ	.	.	.	.	.	.
— Typhaceæ	.	.	.	.	.	.
Class *Dicotyledones.*						
Incompletæ.						
Fam. Ceratophyllaceæ	.	.	.	.	.	.
— Cupuliferæ	.	.	.	.	.	.


MESOZOIC
CAINOZOIC
Trias
Lias
Oolitic Group
Oolite
Pur-beck
Cretaceous Gr.
Weal-den
Creta-ceous
Eocene
Oligocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboni-ferous	Permian
Fam. Salicineæ . . .	.	.	.	.	.	.
— Betulaceæ . . .	.	.	.	.	.	.
— Platanaceæ . . .	.	.	.	.	.	.
— Myricaceæ . . .	.	.	.	.	.	.
— Artocarpeæ . . .	.	.	.	.	.	.
— Lauraceæ . . .	.	.	.	.	.	.
— Proteaceæ . . .	.	.	.	.	.	.
Corollifloræ.						
Fam. Rubiaceæ . . .	.	.	.	.	.	.
— Apocynaceæ . . .	.	.	.	.	.	.
— Ericaceæ . . .	.	.	.	.	.	.
— Vacciniaceæ . . .	.	.	.	.	.	.
— Gentianaceæ . . .	.	.	.	.	.	.
Thalamifloræ.						
Fam. Anonaceæ . . .	.	.	.	.	.	.
— Nymphæaceæ . . .	.	.	.	.	.	.
— Nelumbiaceæ . . .	.	.	.	.	.	.
— Malvaceæ . . .	.	.	.	.	.	.
— Aurantiaceæ . . .	.	.	.	.	.	.
— Sapindaceæ . . .	.	.	.	.	.	.
— Vitaceæ . . .	.	.	.	.	.	.
Calycifloræ.						
Fam. Cucurbitaceæ . . .	.	.	.	.	.	.
— Cornaceæ . . .	.	.	.	.	.	.
— Myrtaceæ . . .	.	.	.	.	.	.
— Rhamnaceæ . . .	.	.	.	.	.	.
— Rosaceæ . . .	.	.	.	.	.	.
— Celastraceæ . . .	.	.	.	.	.	.
— Leguminoseæ . . .	.	.	.	.	.	.

MESOZOIC						CAINOZOIC				
		Oolitic Group		Cretaceous Gr.						
Trias	Lias	Oolite	Pur-beck	Weal-den	Creta-ceous	Eocene	Oligocene	Pliocene	Post-Pliocene	Recent
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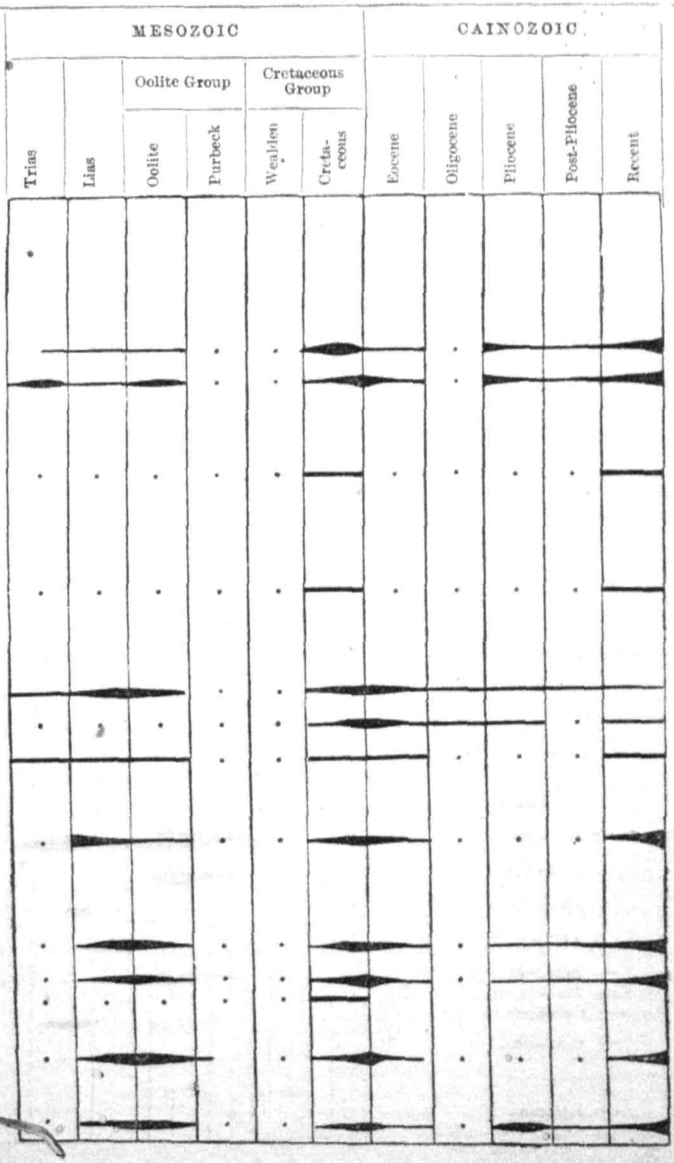
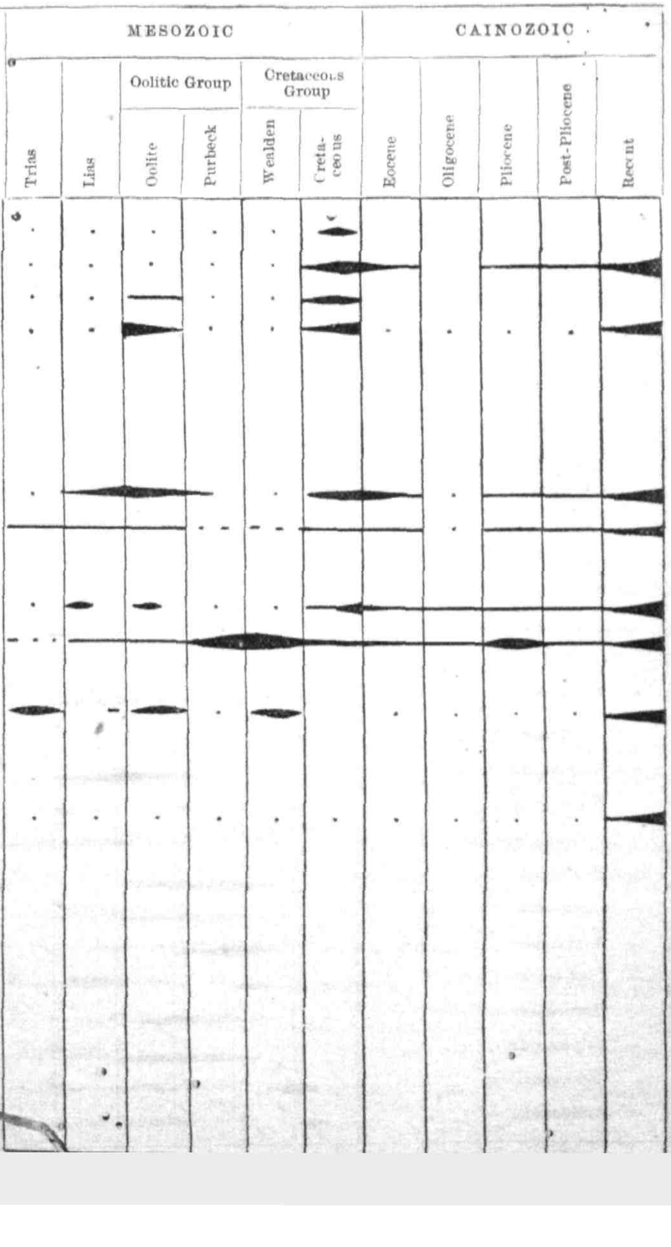
Classes, Orders, and Families	Palæozoic					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
INVERTEBRATA.						
Type **Protozoa.**						
Class Rhizopoda.						
Order Spongida, &c.	—	—	—	—	—	·
— Foraminifera	·	—	—	—	—	—
Type **Cœlenterata.**						
Class Hydrozoa.		—	—	—	—	·
Fam. Graptolitidæ	·	—	—			
Class Alcyonaria.						
Fam. Helioporidæ			—	·	·	·
Class Actinozoa.						
Sect. Rugosa	·	—	—	—	—	—
— Aporosa	·	·	·	—	·	·
— Perforata	·	·	·	·	·	·
— Fungida	·	·	·	·	·	·
Type **Echinodermata.**						
Order Crinoidea	—	—	—	—	—	—
— Cystoidea	·	—	—	—		
— Blastoidea	·	·	·	·	—	
— Ophiuroidea	·	·	—	—	—	·
— Asteroidea	·	—	—	—	·	·
Fam. Marsupitidæ	·	·	·	·	·	·
— Palæchinidæ	·	·	·	·	—	
— Cidaridæ	·	·	·	·	·	·
— Echinidæ	·	·	·	·	·	·


MESOZOIC
CAINOZOIC
Oolite Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Oligocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Fam. Ananchytidæ	·	·	·	·	·	·
— Spatangidæ	·	·	·	·	·	·
— Galeritidæ	·	·	·	·	·	·
— Cassidulidæ	·	·	·	·	·	·
Type **Annelida.**						
Order Tubicola (*Serpulæ*)	—	—	—	—	—	—
Errantia (*Arenicolæ*)	—	—	—	—	—	—
Type **Crustacea.**						
Order Cirripedia, &c.	·	·	—	·	·	·
— Ostracoda		—	—	—	—	—
— Phyllopoda	—	—	—	—	—	
Merostomata.						
— Eurypterida	·	·	—	—	—	
— Xiphosura	·	·	—	·	—	
Group **Trilobita.**						
Fam. Phacopidæ	·	—	—	—		
— Cheiruridæ	·	—	—	—		
— Acidaspidæ	·	—	—			
— Cyphaspidæ	·	—				
— Harpedidæ	·	—	—	—		
— Calymenidæ	·	—	—	—		
— Conocephalidæ	—					
— Paradoxidæ	—					


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Oligocene
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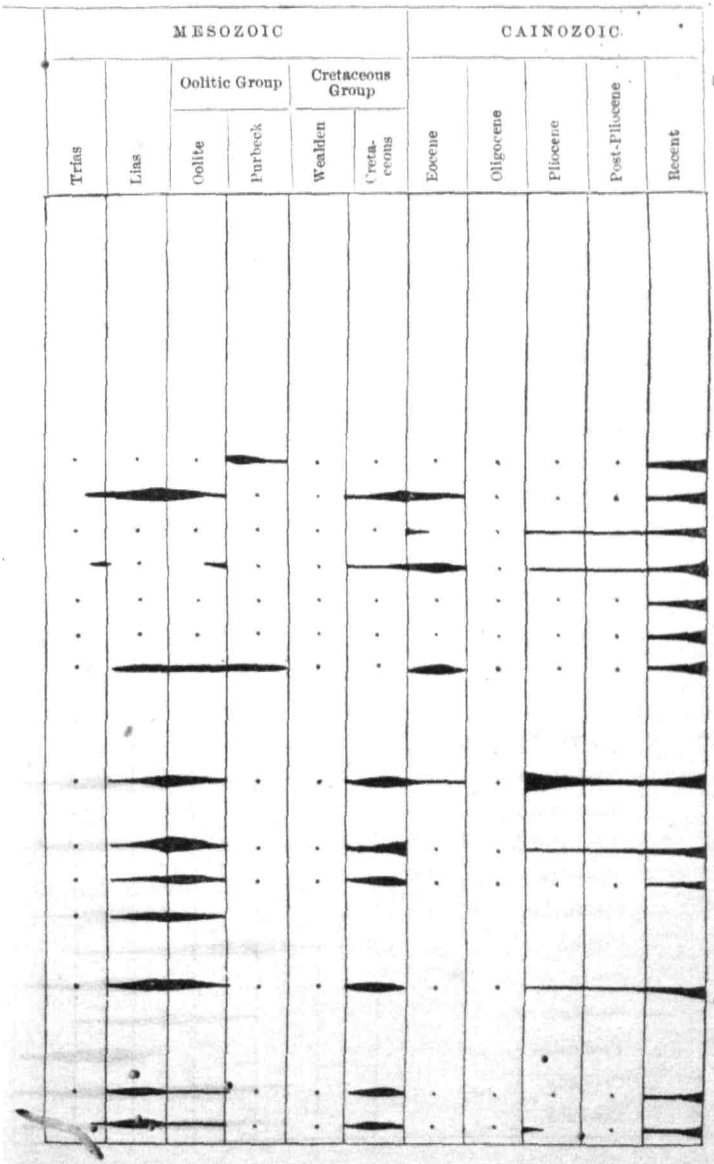
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Fam. Olenidæ	—	—				
— Asaphidæ	·	—	—			
— Bronteidæ	·	—	—	—		
— Proteideæ	·	·	—	—	—	
— Trinucleidæ	·	—	—			
— Agnostidæ	—	—				
Sub-Class Malacostraca.						
Order Isopoda	·	·	·	·	·	—
— Macrura	·	·	·	·	—	—
— Anomura	·	·	·	·	·	·
— Brachyura	·	·	·	·	·	·
Class Arachnida	·	·	·	·	—	·
Class Myriapoda	·	·	·	·	—	·
Class Insecta	·	·	·	·	—	·
Type **Molluscoida.**						
Class Bryozoa	·	—	—	—	—	—
Class Brachiopoda						
Fam. Terebratulidæ	·	·	·	—	—	—
— *Thecididæ*	·	·	·	·	·	·
— Spiriferidæ	·	·	—	—	—	—
— Orthidæ	—	—	—	—	—	
— Rhynchonellidæ	·	·	—	—	—	—
— Strophomenidæ	·	—	—	—	—	
— Productidæ	·	·	·	—	—	—
— Craniadæ	·	—	—	—	—	—
— Discinidæ	·	—	—	—	—	—


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Cretaceous
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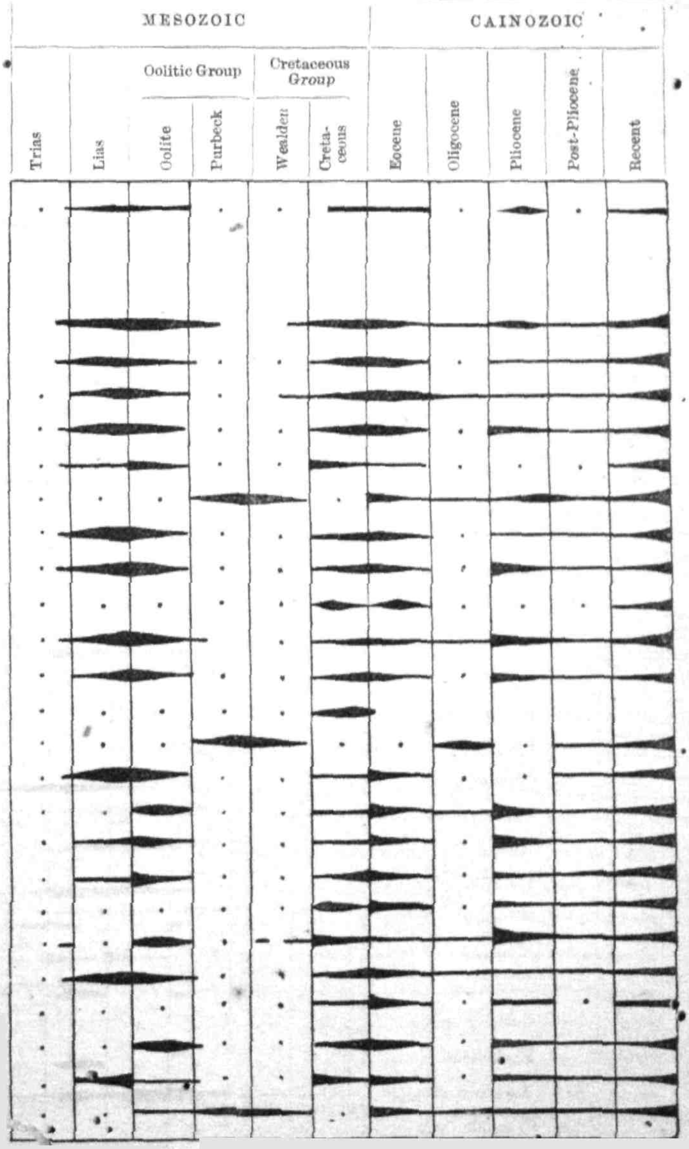
Oligocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families		Palæozoic					
		Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Bra-chio-poda	Fam. Lingulidæ . .	—	—	—	—	—	—
	— *Calceolidæ* . .	·	·	·	—		
Class Lamellibranchiata.							
Asiphonida	Fam. Ostreidæ . . .	·	·	·	·	·	·
	— Aviculidæ . .	·	—	—	—	—	—
	— Mytillidæ . .	·	—	—	—	—	—
	— Arcadæ . .	—	—	—	—	—	—
	— Trigoniadæ . .	·	—	— —	—	—	—
	— Unionidæ . .	·	·	·	—	·	·
	— Limidæ . . .	·	·	·	·	·	·
	— Pectinidæ . .	·	·	·	·	·	—
Siphonida	— *Chamidæ* . .	·	·	·	·	·	·
	— Cardiidæ . .	·	·	—	—	—	·
	— *Lucinidæ* . .	·	·	·	·	·	·
	— Hippuritidæ .	·	·	·	·	·	·
	— Cycladidæ . .	·	·	·	·	·	·
	— Cyprinidæ . .	·	·	·	—	—	—
	— Veneridæ . .	·	·	·	—	·	·
	— Mactridæ . .	·	·	·	·	·	·
	— Tellinidæ . .	·	·	—	—	—	—
	— Solenidæ . .	·	·	—	·	—	—
	— Myacidæ . .	·	·	—	—	—	·
	— Anatinidæ . .	·	·	—	·	—	—
	— Gastrochænidæ . .	·	·	·	·	·	·
	— Pholadidæ . .	·	·	·	·	—	·
	— Nuculidæ . .	—	—	—	—	—	—
	— Cyrenidæ . .	·	·	·	·	·	·


MESOZOIC
CAINOZOIC
Oolitic Group
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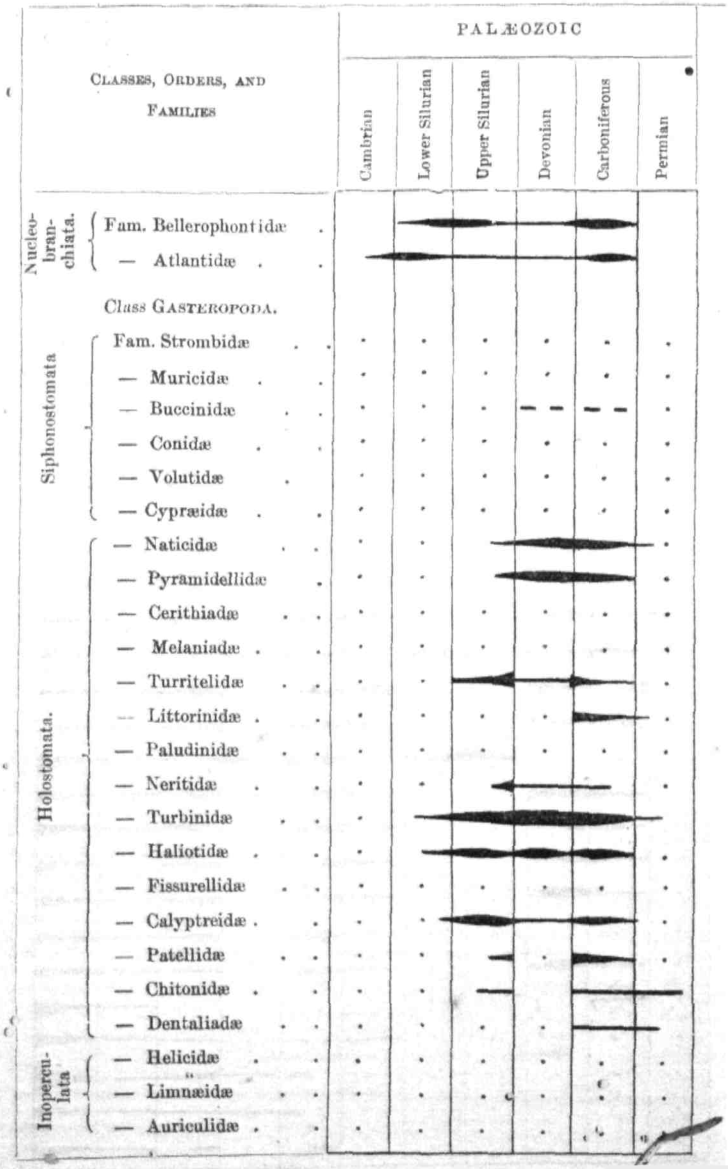
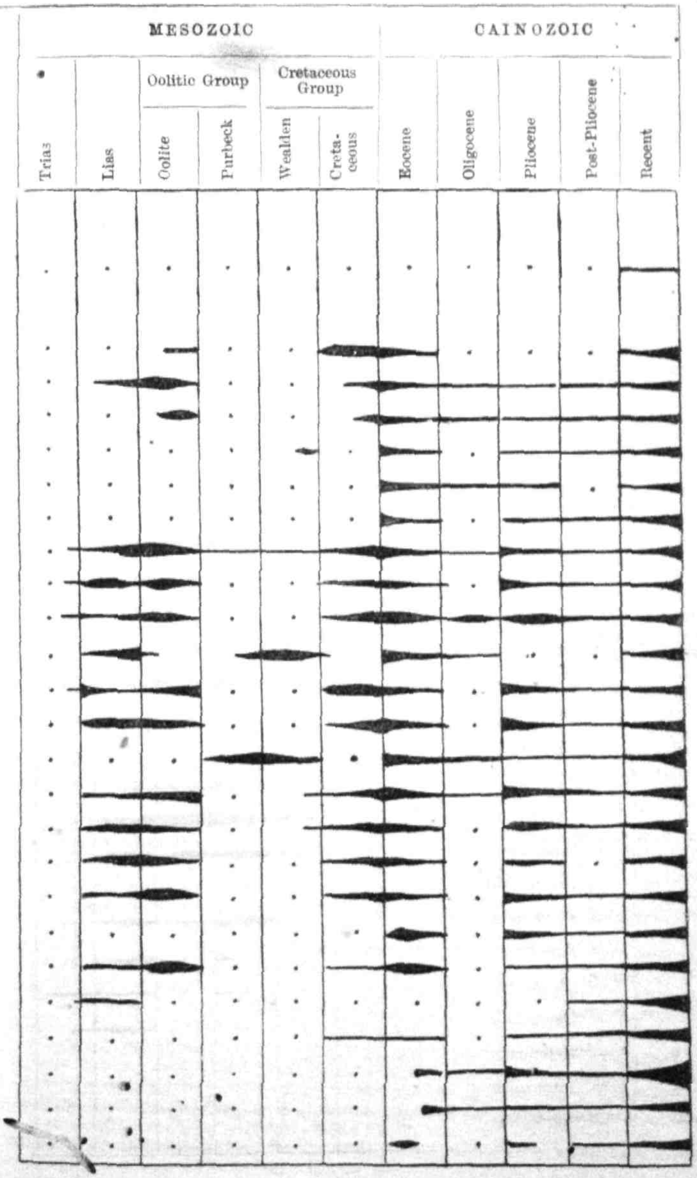

PALÆOZOIC
Classes, Orders, and Families
Cambrian
Lower Silurian
Upper Silurian
Devonian
Carboniferous
Permian
Nucleo-branchiata.
Fam. Bellerophontidæ
— Atlantidæ
Class Gasteropoda.
Siphonostomata
Fam. Strombidæ
— Muricidæ
— Buccinidæ
— Conidæ
— Volutidæ
— Cypræidæ
Holostomata.
— Naticidæ
— Pyramidellidæ
— Cerithiadæ
— Melaniadæ
— Turritelidæ
— Littorinidæ
— Paludinidæ
— Neritidæ
— Turbinidæ
— Haliotidæ
— Fissurellidæ
— Calyptreidæ
— Patellidæ
— Chitonidæ
— Dentaliadæ
Inopercu-lata
— Helicidæ
— Limnæidæ
— Auriculidæ


MESOZOIC
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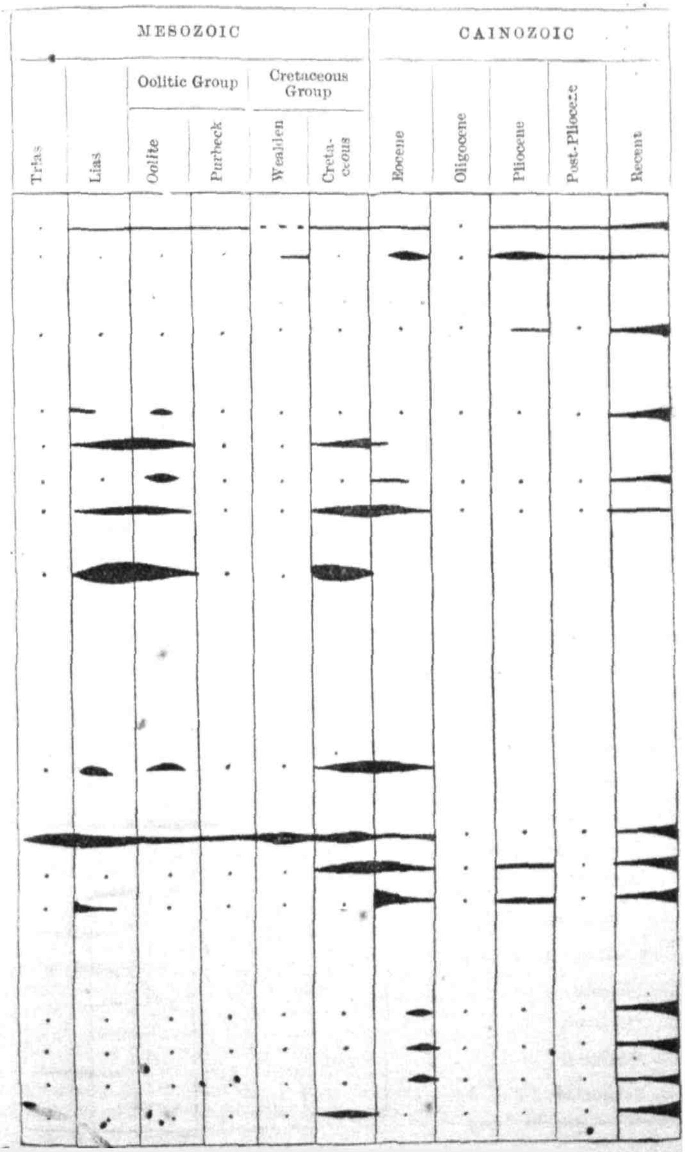
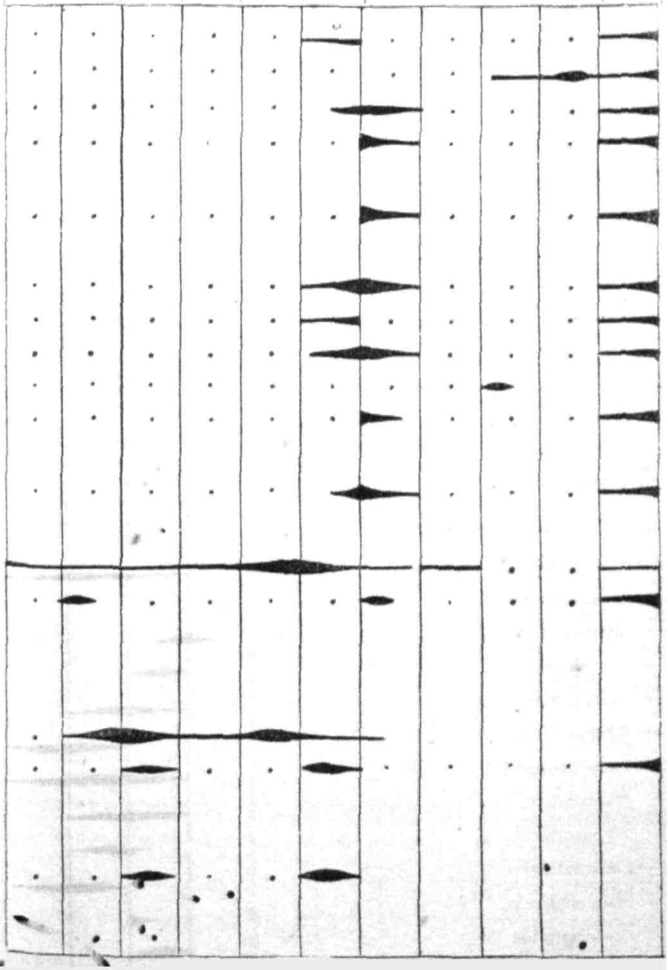
Oligocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic: *Cambrian*	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Tectibranchiata — Fam. Tornatellidæ	·	·	·	·	·	·
— Bullidæ	·	·	·	·	·	·
Class Pteropoda.						
Fam. Hyleidæ	·	—	—	—	—	—
Class Cephalopoda.						
Dibranchiata — Fam. Teuthidæ	·	·	·	·	·	·
— Belemnitidæ	·	·	·	· ·	·	·
— Sepiadæ	·	·	·	·	·	·
Tetrabranchiata — Nautilidæ	·	—	—	—	—	—
— Orthoceratidæ	—	—	—	—	—	
— Ammonitidæ	·	·	·	·	—	·
VERTEBRATA.						
Class Pisces.						
Order Elasmobranchii.						
Sub-Order *Holocephali.*						
Fam. Edaphodontidæ	·	·	·	·	·	·
Sub-Order *Plagiostomi.*						
Fam. Cestraphori	·	·	· —	—	—	—
— Squalidæ (Selachii)	·	·	·	·	·	·
— Raidæ	·	·	·	·	—	·
Order Teleostei.						
Sub-Order A. *Malacopteri.*						
Fam. Siluridæ	·	·	·	·	·	·
— Cyprinidæ	·	·	·	·	·	·
— Characini	·	·	·	·	·	·
— Salmonidæ	·	·	·	·	·	·

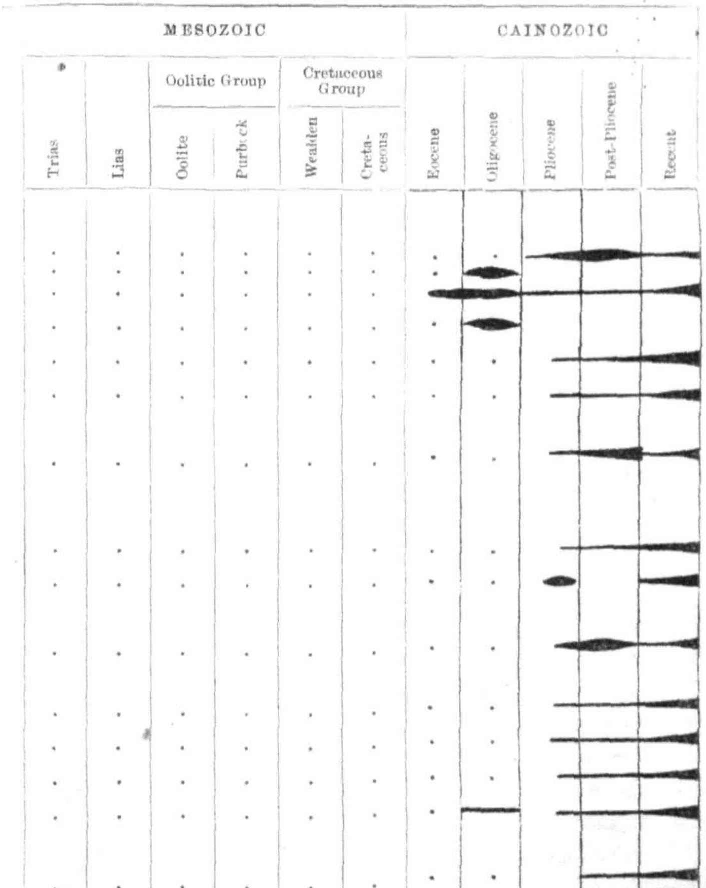

MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Oligocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	Palæozoic: Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Fam. Scopellidæ . . .	.	.	.	.	.	.
— Esocidæ . . .	.	.	.	.	.	.
— Clupeidæ	.	.	.	.	.	.
— Murænidæ . . .	.	.	.	.	.	.
Sub-Order B. *Anacanthini.*						
Fam. Gadidæ	.	.	.	.	.	.
Sub-Order C. *Acanthopteri.*						
Fam. Percidæ . . .	.	.	.	.	.	.
— Mugilidæ	.	.	.	.	.	.
— Scomberidæ . . .	.	.	.	.	.	.
— Squammipennes . . .	.	.	.	.	.	.
— Lophiidæ . . .	.	.	.	.	.	.
Sub-Order D. *Pharyngognathi.*						
Fam. Scomberesocidæ . . .	.	.	.	.	.	.
Order Ganoidei.						
Sub-Order *Lepidosteidæ* (*Saurodei*)	.	.	.	—	—	—
Fam. Chondrosteidæ . .	.	.	.	.	.	.
— Cephalaspidæ . . .	.	.	—	—		
— Placodermi . . .	.	.	.	—		
— Acanthodidæ . . .	.	.	.	—	—	
— Pycnodontidæ . .	.	.	.	.	—	—
— Crossopterigidæ . . .	.	.	.	—	—	—
— Saurodipterni . .	.	.	.	—	—	
— Glyptodipterni . . .	.	.	.	—	—	
— Cælacanthini . . .	.	.	.	.	—	—
— Phaneropleurini . .	.	.	.	—		—
— Ctenodipterini . .	.	.	.	—	—	

MESOZOIC						CAINOZOIC				
		Oolitic Group		Cretaceous Group						
Trias	Lias	Oolite	Purbeck	Wealden	Cretaceous	Eocene	Oligocene	Pliocene	Post-Pliocene	Recent



Classes, Orders, and Families	Palæozoic					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Sec. B. *Artiodactyla.*						
Fam. Hippopotamidæ	.	.	.	.	.	.
— Hyopotamidæ	.	.	.	.	.	.
— Suidæ	.	.	.	.	.	.
— Anoplotheridæ	.	.	.	.	.	.
— Cervidæ	.	.	.	.	.	.
— Bovidæ	.	.	.	.	.	.
Order Proboscidea.						
Fam. Elephantidæ	.	.	.	.	.	.
Order Carnivora.						
Sec. 1. *Pinnigrada.*						
Fam. Phocidæ	.	.	.	.	.	.
— Trichicidæ	.	.	.	.	.	.
Sec. 2. *Plantigrada.*						
Fam. Ursidæ	.	.	.	.	.	.
Sec. 3. *Digitigrada.*						
Fam. Mustellidæ	.	.	.	.	.	.
— Hyænidæ	.	.	.	.	.	.
— Canidæ	.	.	.	.	.	.
— Felidæ	.	.	.	.	.	.
Order Rodentia.						
Fam. Leporidæ	.	.	.	.	.	.
— Castoridæ	.	.	.	.	.	.
— Muridæ	.	.	.	.	.	.
Order Cheiroptera.						
Fam. Vespertilionidæ	.	.	.	.	.	.
— Rhinolophidæ	.	.	.	.	.	.
Order Insectivora.						
Fam. Talpidæ	.	.	.	.	.	.
— Scricidæ	.	.	.	.	.	.


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Oligocene
Pliocene
Post-Pliocene
Recent

NOTE.

The Succession of the Rocks of the North-Western Highlands.—The relation of the fossiliferous Lower Silurian strata of this region to the metamorphic rocks has been noticed in Chap. XXVIII. of this edition, and the conflicting views of Murchison and many other geologists regarding the succession are stated on pp. 453 and 454. Dr. Callaway's theory, which has resulted from very careful surveying, is given there in illustration of the belief of many of the ablest geologists of the day. Whilst these pages were passing through the press, the Director-General of the Geological Survey of the United Kingdom withdrew his assent to the views of the great man to whom Geology owes so much. It will therefore be necessary for students to study the opinions of Dr. Callaway only, and these will be found on p. 454.

Mr. Searles Wood, F.G.S. has lately described an Older Pliocene deposit at St. Erth, north-east of Penzance.

THE EDITOR.

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